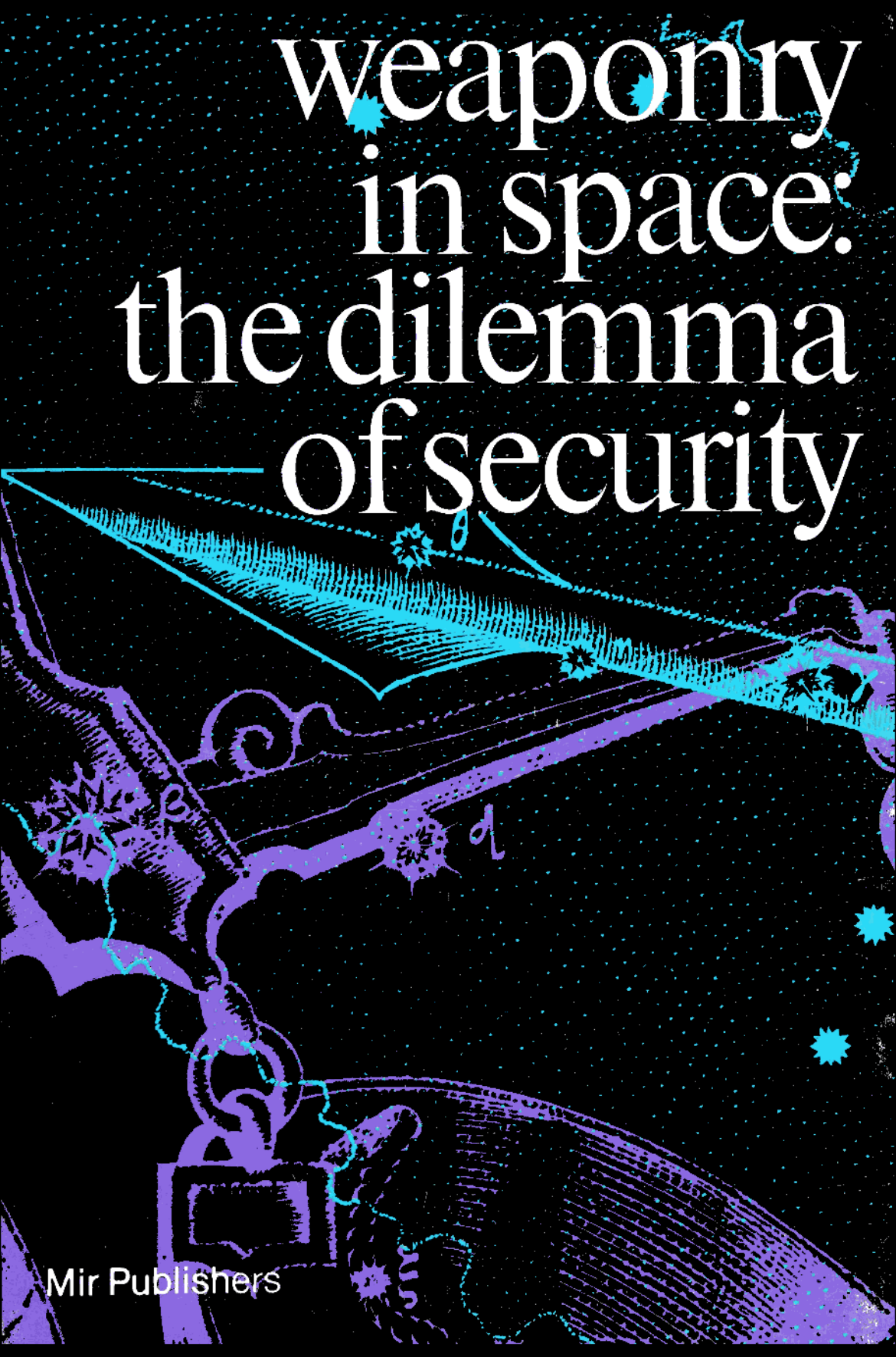
weaponry in space: the dilemma of security



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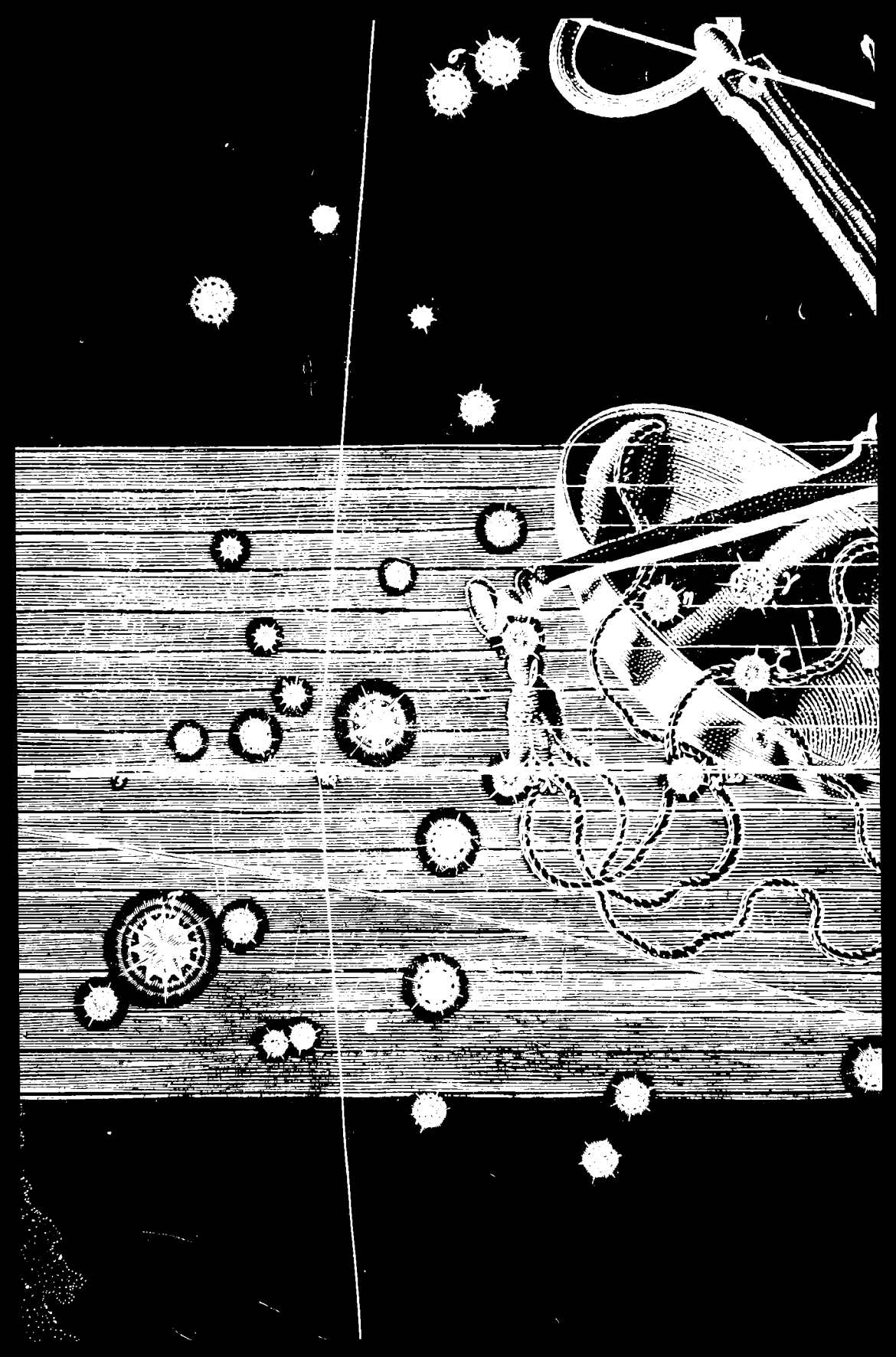
Soviet Scientists' Committee
for the Defense of Peace
Against Nuclear Threat

The threat of nuclear war and the hope for its prevention have become fundamental moral and political challenges to all of humankind. They cannot be dealt with primarily as problems for scientific and technical manipulation. The building of more nuclear weapons and the improvement of their technical sophistication are not the path to global security. There is no hope that a technical 'breakthrough', such as weapons systems in space, will provide clear superiority or significant protection.

A statement from a
Conference of Scientists
and Religious Leaders.
Bellagio, Italy.
November 23, 1984



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weaponry in space:

the dilemma of security

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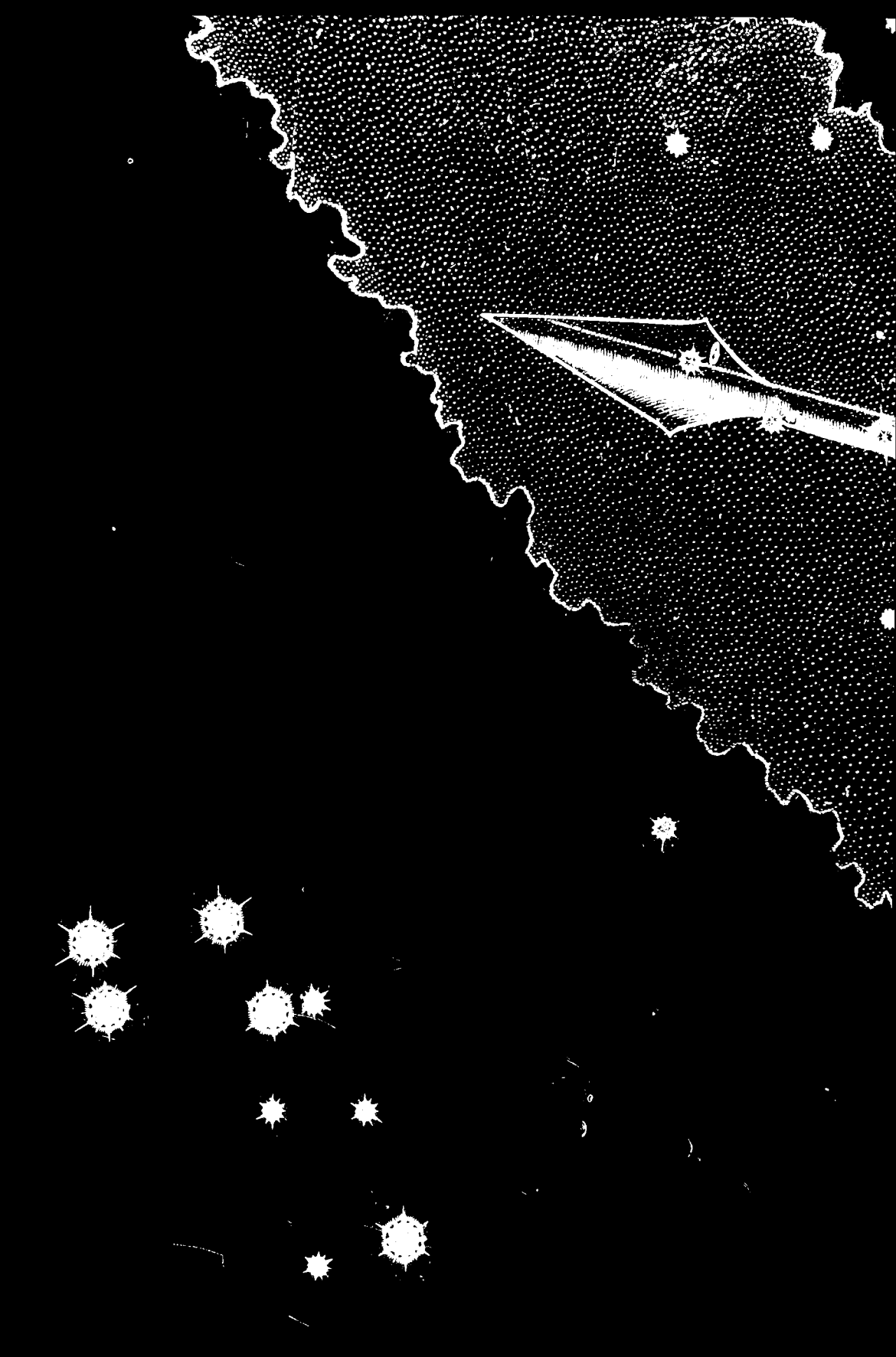

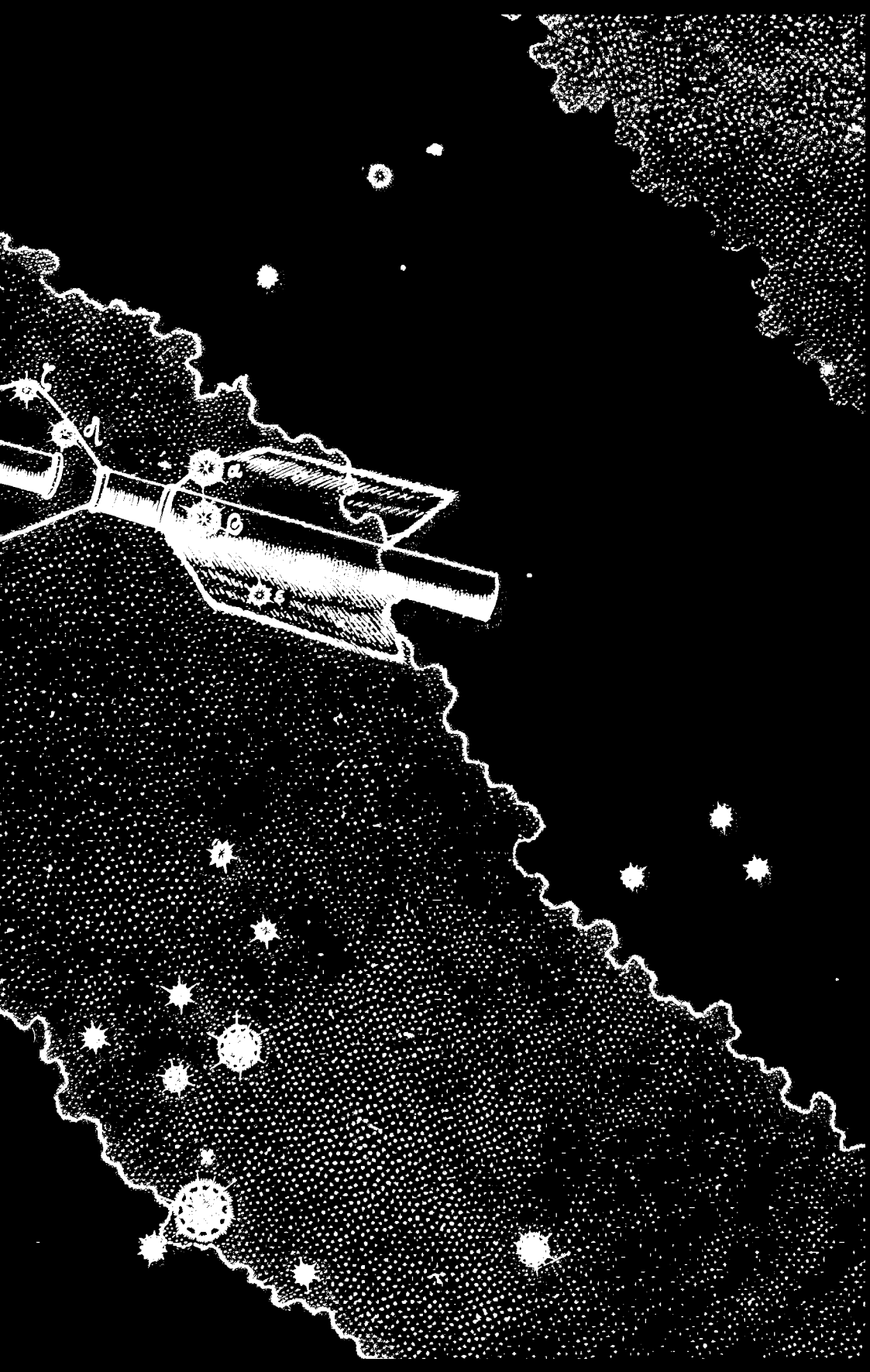
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Introduction

Soviet scientists, just like some of their colleagues from other countries, including the USA, even before President Reagan's 'Star Wars' speech on March 23, 1983, paid attention to the enormous dangers for the stability of the strategic balance and international security, which might come about should the United States attempt to develop and deploy a comprehensive ballistic-missile defense. It was noted in the Declaration of the Heads and Representatives of 36 Academies of Sciences (including the USSR Academy of Sciences and the National Academy of Sciences, USA) signed in Rome in September 1982 that there is no defense against nuclear weapons and that the only way of ensuring security and reducing the threat of a catastrophic war is to curb and reduce nuclear weapons until they are totally eliminated.

As is known now, this and other similar attitudes of the scientific community have been ignored by the US Administration. Following the above-mentioned speech by the President of the United States, a program was worked out and promulgated, a program that became known as the Strategic Defense Initiative (SDI), which became a key element of the military and political course of the current US Administration.

If the White House hoped that American and international public opinion would support this program because of its allegedly defensive nature, these hopes failed. The Initiative encountered stiff opposition in various circles, including those of prominent American and West European scientists. The concept of deploying a comprehensive space-based ballistic-missile defense incited a heated debate in the international community in which Soviet scientists took an active part. It is worth noting that now that we are witnessing a rise in the antiwar, antinuclear movement around the world, many military and technological questions began to be discussed by the public and scientists in many countries in much detail.

The Soviet Scientists' Committee for the Defense of Peace Against Nuclear Threat was elected at the All-Union Conference of Scientists for Ridding Mankind of Nuclear War, for Disarmament and Peace held in Moscow on May

17–19, 1983. It includes 25 scientists from different branches of knowledge. The Committee decided to conduct a study of the scientific, technological, military, strategic, and political aspects of the deployment of a comprehensive space-based ballistic-missile defense (BMD) (with emphasis on the space-based components, because these figured prominently in the SDI).

To this end, a working group was formed that included, along with some of the members of the Committee, a group of experts, notably from the Space Research Institute of the USSR Academy of Sciences, the Institute of the World Economy and International Relations of the USSR Academy of Sciences, and the Institute of the USA and Canada Studies of the USSR Academy of Sciences. A distinctive feature of this Working Group was that it brought together specialists in natural and social sciences, in engineering and military strategy. Some of the members of the Working Group had experience both in natural (engineering) sciences and in social sciences.

Important contributions were made by a number of experienced consultants of the Committee, well-known authorities in military sciences and strategic planning: Prof. Colonel General N. A. Lomov (retired) of the General Staff of the USSR Armed Forces, Prof. Lieutenant General M. A. Mil'stein (retired), Colonel L. S. Semeiko (retired), Cand. Sc. (Mil.). The members of the Committee and major scientists in their respective fields also contributed to the treatment of some aspects, they are: Academician I. G. Gverdtsiteli of the Georgian Academy of Sciences, Prof. S. P. Kapitza, D. Sc. (Phys.-Math.), Academician B. V. Rauschenbach (a close associate of Chief Designer Academician S. P. Korolev). Specifically, Rauschenbach made a number of valuable comments concerning the issues of reliability and fashioning of a complicated system from its elements and components.

After a series of discussions among the Soviet scientific community, the tentative results of the study by the Working Group were reported at an international seminar in Italy in August 1983 , where representatives of the Committee and the USSR Academy of Sciences had a heated debate with those American scientists who represented the relatively tenuous group of SDI advocates among the US academic world. The tentative results passed the acid test successfully. In November 1983 the early version of the report was issued in brochure form (only in Russian) .

The final forms of the report were issued in Russian and English in April 1984. Up-dated and enlarged versions were published in October 1985 and February 1986.

In 1984–86 also appeared reports by the Union of Concerned Scientists of the USA, the US Congressional Office of Technology Assessment, a group of Stanford University workers headed by the major US physicist S. Drell, a joint working group of the American Academy of Arts and Sciences and Cornell University headed by Prof. F. Long. Other studies were published by the promi-

nent physicist Prof. R. Garwin in IBM, a number of West German scientists, and a group of French specialists. These groups essentially came to the same conclusions as the report by Soviet scientists, although each of the studies was conducted independently and was based on different techniques and models.

The Soviet research methodology and techniques relied on the principles of systems analysis and operations research. Special models were developed. Much attention was paid to the rigorous, correct formulation of problems, definition of the stages of the study considering its comprehensive and multidisciplinary character. The technological, strategic and political assessments contained in this book are a summary of the studies and developments carried out by the members of the Working Group and subgroups.

In their approach to the assessment of the potential implications of a full-scale space-based ballistic-missile defense for the political situation in the world, for the strategic balance and its stability, the authors agreed that nowadays we witness a most complicated macrosystem of strategic interplay .

Today's strategic balance is determined by a host of intertwined quantitative and qualitative factors characterizing the forces of the two sides, and of factors characterizing the strategic situation. The interplay of these factors can be represented as a complex dynamic macrosystem, whose key element is nuclear, notably strategic, weapons. The state of this macrosystem depends not only on nuclear weapons, but also on other elements and factors. There is, in particular, the well-known close dialectical connection between the offensive means of both sides and between the offensive and defensive means of the opposing sides and of each of them individually.

The dialectics of the strategic balance is such that the appearance (or even development, testing, let alone deployment) on one side of a new weapon, defensive or offensive, that claims to have utility may bring about a marked disturbance of the balance, for which the other side compensates by deploying its weapons, thereby restoring the balance at a higher level, which makes for a greater degree of instability.

At the beginning of the 1970s, when the USA and the USSR started talks on strategic arms, they recognized that there existed a strategic parity and an inexorable link between strategic offensive and defensive weapons on either side. This understanding found its reflection in the signing in 1972 of the Treaty on the Limitation of Anti-Ballistic-Missile Systems (of unlimited duration) and the SALT I Treaty.

To maintain the balance under conditions when the USA started a fresh round of arms race nearly every five years by implementing ever new programs of strategic buildup, the USSR had to respond in order to ensure its security, and not to allow US military supremacy. So, a complex of such measures to restore the military balance was instituted by the USSR and its Warsaw Treaty allies in response to the deployment in Western Europe of Pershing 2 ballistic missiles and

ground-based long-range cruise missiles. The USSR thus restored the balance tipped by the USA, but now at a higher level: with more nuclear warheads on both sides aimed at each other and less time allowed for making decisions in case of a nuclear attack or some unintentional dangerous situation. Serious damage was inflicted to the trust between the states.

One can speak definitely of some law of 'diminishing effect' in the tight strategic interplay, when investments in nuclear arms (considering the already existing enormous arsenals and the other side's countermeasures) become ever less effective in terms of real changes in the strategic balance.

The world, it seems, has crossed the line beyond which any further accumulation and improvement of nuclear weapons is not only dangerous but senseless.

Moreover, the endless buildup of nuclear weapons as such generates fears in peoples and governments, heightens nervousness and the threat of nuclear war, among other things due to a technical or human error, a danger that increases as nuclear arsenals become larger.

One should not overlook the fact that the presence of enormous arsenals of nuclear arms and the ever growing perception of the threat of a universal holocaust erode the psyche of a great number of people. Psychiatrists, neuropathologists and psychologists indicate that the incidence of neuroses in the present world has gone up, and Academician N. P. Bekhtereva, a member of the Committee, writes that one common cause of neurosis is the arms race, the fear of a nuclear war. The threat to the human psyche increases when humanity faces the fatal danger of its total destruction [0.4].

Many scientists, soldiers, statesmen and politicians in the West admit that for about 15 years now, there exists such an alignment of nuclear arsenals of the sides that neither side is able to gain a victory in nuclear war, even if it initiates it. American military planners christened this strategic situation as 'mutually assured destruction' (MAD). Some Western spokesmen even hold that it is this state of the 'balance of terror,' its perception and use by both sides as a guiding principle, that is the main assurance of peace, that factor which is to take credit for the fact that there has been no third world war so far.

But we believe that this safeguard is too fragile. Without a doubt, should the USA and the USSR (just like any other country) have no nuclear weapons, peace safeguarded by large-scale political security-building measures would be much more stable. Peace would be more sound not with the 'balance of terror' (especially in a tenser political climate with the sides having at their disposal huge arsenals of nuclear arms and missiles), but with mutual reduction and destruction of nuclear arsenals, with the political situation normalized, with all disputes handled by negotiations, with the economic, scientific and cultural cooperations developed and deepened, with wider contacts between peoples encouraged. This would all make for more confidence and trust. The construction of a solid system

of international security without nuclear arms is the object of all the Soviet proposals concerning the complete and universal elimination of nuclear arms by the year 2000, contained in the January 15, 1986, Statement by General Secretary of the CPSU Central Committee M.S.Gorbachev.

Strange as it may seem at first sight, the MAD concept is criticized in the West not only by pacifists but also by politicians, scientists, and some of the military, who are guided by motives far from a love for peace. They do not accept a reduction of arms and disarmament on the principle of equality and equal security. On the other hand, they are also unhappy with the MAD principle, which implies the recognition of a kind of 'nuclear stalemate' inherent in parity, which rules out the use of force as an active tool in policy, thereby eliminating the need for the further development of weapons.

The main direction in which the USA is moving to break out of the 'nuclear stalemate' is the plan to develop and deploy a comprehensive space-based ballistic-missile defense, called the Strategic Defense Initiative (SDI) program.

Since about the end of the 1950s one of the most important premises of US military strategy was the impossibility to reduce the destructive consequences for the USA of a total nuclear war down to an 'acceptable' level. This premise resulted from the creation in the USSR of intercontinental nuclear delivery vehicles and the growth on either side of nuclear arsenals. Following relatively short-term strategic experiments with the concepts of 'counterforce' and 'damage limitation' early in the 1960s (which meant cutting US losses by striking first at some of the Soviet strategic forces at launch sites), the official US military doctrine came to recognize in some form or other the MAD situation. So, as early as the 1960s, McNamara, US Secretary of Defense in President Kennedy's Administration, concluded that an 'unacceptable damage' for both sides is the destruction from 1/4 to 1/3 of the population and from 1/2 to 2/3 of the industrial potential. He estimated that this could be achieved by a nuclear strike of a total yield of 400 Mt. With some corrections ('selective strikes,' 'limited nuclear war,' and other concepts), this principle remained the main military doctrine of the USA from the end of the 1960s to the beginning of the 1980s. According to this doctrine, with the nuclear arsenals available on either side the USA ensures its security not by being able to cut its losses in a global nuclear war down to an acceptable level, but by deterring the other side from using nuclear weapons by the threat of inflicting similar or greater damage. The concepts and technologies of directly protecting the country's territory from nuclear weapons disappeared from official documents and statements of the US Government, including the Department of Defense. Antiballistic-missile defenses became the subject of discussion almost exclusively because of the higher level of survivability of the US strategic forces themselves.

President Reagan's speech of March 23, 1983, and the SDI program put forward in it mark a radical change in the key concepts of US military and political strategy. Deterrence, associated with the ability of both great powers to destroy each other even by a retaliatory strike, was proclaimed to be 'evil' and the only alternative was proclaimed to be the concept of the direct protection of the entire US from nuclear weapons by all possible means, including various forms of space-based ballistic-missile defense, which, in the opinion of some US experts, would play a decisive role in the creation of a 'comprehensive antimissile shield.' This reorientation in official US strategy, if established, would create a fundamentally new scientific, strategic, political, and psychological context for making further decisions about military programs of both offensive and defensive natures. Therefore, the realization of the SDI program would be a major obstacle to a world without nuclear weapons.

However, before dealing with these implications, it would make sense to turn to some of the scientific and technological aspects of the proposed space-based ballistic-missile-defense system.

Chapter 1

Hypothetical space-based components of a ballistic-missile defense

This chapter deals with an analysis of technological capabilities and constraints inherent in the antiballistic-missile weapons that are being considered in connection with the Strategic Defense Initiative [1.1].

A number of assessments of the technological aspects of creating combat components of a large-scale ballistic-missile-defense (BMD) system have been made by the Soviet Scientists' Committee for the Defense of Peace Against Nuclear Threat in 1983 [illegible], the Union of Concerned Scientists (USA) in 1984 [illegible], the Center for International Security and Arms Control, Stanford University (USA) in 1984 [illegible], the Congressional Office of Technology Assessment (USA) in 1984–85 [illegible], and also in a number of papers by Soviet and US scientists published in 1983–85. The concept behind the SDI is the development and deployment of systems designed to destroy intercontinental ballistic missiles (ICBM's) and submarine-launched ballistic missiles (SLBM's) throughout their trajectories. This is the main departure of the proposed space-based ballistic-missile-defense system from the ABM systems that were developed and deployed in the late 1960s and early 1970s and were then banned by the US–Soviet ABM Treaty of 1972 of unlimited duration. Earlier ABM systems were only concerned with *terminal-phase* defense against ballistic missiles.

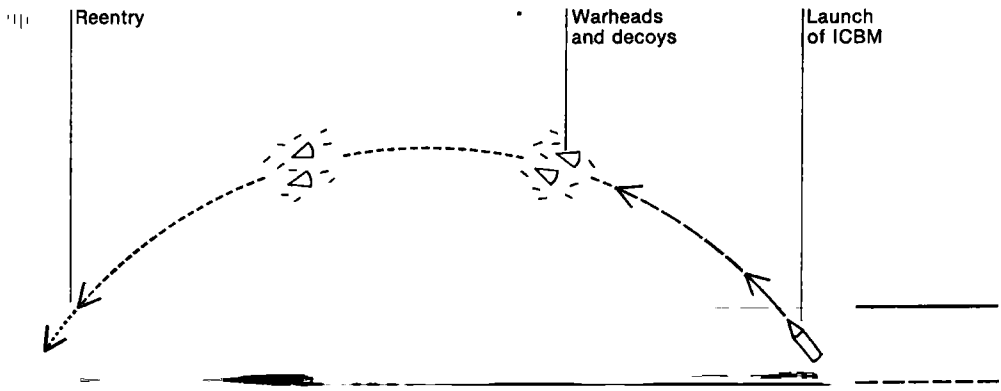
We now address ourselves to the trajectory phases of a ballistic missile concentrating on those aspects which are especially important in terms of implementing a reliable BMD.

A missile's trajectory is normally divided into four phases (Figure 1.1):

— a *boost phase*, when boosters accelerate the missile to a final velocity (6–7 km s^{-1});
— a *post-boost*, or *busing*, phase, when multiple independently targetable reentry vehicles (MIRV's) or warheads and penetration aids are released;
— a *midcourse*, or *ballistic*, phase, when all the objects launched travel in ballistic trajectories;
— a *terminal* phase, when the warheads and penetration aids reenter the

dense layers of the atmosphere, with the lighter penetration aids affected by atmospheric drag.

Both advocates and opponents of the SDI consider that for a BMD to be effective it must start intercepting attacking ICBM's as early as the boost phase.



There are several reasons for this:

1. The number of targets to be handled in the boost phase is minimal (before the release of the MIRV's and the decoys).
2. An ICBM in boost phase is easily detectable by acquisition and tracking means due to the bright plumes produced by the burning boosters.
3. A missile is a much larger target than warheads, and so it is more readily detectable, and hence more vulnerable, because its skin, mainly walls of fuel compartments, is harder to protect from thermal or impact kill than warheads.

For the sake of our analysis the boost phase of the trajectory can be characterized by two parameters—the *burn-out time* and *burn-out altitude*.

The time required for a missile to reach its final velocity at the end of its boost phase imposes time constraints on respective components of a BMD system and predetermines the firing rate of the defensive weapons in case of a massive missile attack. The burn-out altitude dictates the technologies needed to destroy the attacking ICBM's. The most important point here is whether a booster burns out above or below the top of the atmosphere (which is assumed throughout to be at an altitude of 100 km).

For current ICBM's typical burn-out times are about 200 s, and burn-out altitudes 200–350 km . Some of the latest US technological assessments indicate that it is possible in principle to reduce burn-out times down to 50 s, and burn-out altitudes down to 80–90 km. Such fast-burn boosters would change the entire BMD concept dramatically.

The above figures suggest that an ICBM in boost phase can only be observed from space. In fact, owing to the curvature of the earth's surface, a missile at an altitude of 200 km is only detectable by sensors within a range of 1,600 km from ground, and within a range of 2,000 km from an altitude of 15 km. With the size of the USSR's territory as it is, US sensors, even if stationed near the Soviet frontiers, would be unable to locate and track an ICBM launch from, say, Central Siberia.

The most important characteristic of the boost-phase defense components deployed in space is their 'kill' radius. Other important characteristics are defensive resources and firing rates. A combination of these characteristics, the boost-phase parameters and the requirement that any of the opponent's ICBM fields or SLBM submarine deployment areas be within reach of one or several of the battle stations at all times dictates how many of the stations are needed and how they should be deployed in space. And the number of space-based battle stations in turn defines the technological and economic aspects of a BMD system. This number is difficult to gauge at present since none of the parameters mentioned above is known with certainty. According to optimistic US estimates several tens of stations will be required but pessimistic estimates put the figure in the thousands. These estimates have become a major subject in a debate that flared up in the United States at the end of 1984. We are going to address this question in more detail later.*

The post-boost phase retains some of the features of the boost phase. The release of individual warheads from the bus requires intermittent operation of thrusters, thus enabling the tracking system of a BMD to identify the bus and get a fix on it. If then the tracking system measures the velocity vector of the bus, the trajectory of the latter can be predicted within a fairly high accuracy.

The warheads are not all released at once, and so the defender has some time to kill several warheads on one shot. But in post-boost phase kill mechanism must change, since now the target is not the relatively vulnerable fuel compartments but the bus or the MIRV's themselves.

The most important parameters for a BMD in the midcourse phase are the maximal duration times and the maximal number of targets, including decoys.

The midcourse phase for a 10,000-km ballistic missile lasts about 20–25 minutes. For this range the optimal minimum-energy apogee is 1,000–1,500 km. Less economical trajectories are possible—depressed or lofted—and they also have different final times. Some US reports indicate that for SLBM's and MRBM's (medium range ballistic missiles which can be used, say, in Europe) depressed trajectories with short final times hold promise. Some of the midcourse phase of their trajectories will lie in the upper atmosphere and the duration of flight of the missile in this phase will be shortened markedly.

The number of warheads and decoys may be larger by far than that of missiles launched. Each ballistic missile can carry up to 10 MIRV's and about the

same number of decoys, which completely resemble a warhead during reentering the atmosphere, and up to 100 simpler penetration aids which are intended to saturate a BMD in the midcourse phase. Penetration aids may be thin-walled balloons made from metal or metallized film, some of them may even harbour real warheads. In this situation the defense is faced with the dilemma of either destroying all the targets indiscriminately or sorting out the true warheads from the decoys. Both tasks pose problems of about the same dimension.

Many US strategic analysts assume that a major nuclear exchange in a hypothetical conflict between the two superpowers will occur across the North Pole. Although it should be possible to deploy ballistic-missile-defense systems on ground to counter an attack in midcourse, space-based defensive systems seem to be more promising. These will have to be space-based weapons in polar or near-polar orbits with altitudes of about 1,000 km.

Depending on its sense of revolution in a polar orbit a battle station may either fly in the opposite direction to attacking warheads with a relative velocity of 15 km s^{-1}, or in the same direction, slowly gaining on them at 1 km s^{-1}. Satellites of the first type are suitable for attacking targets, of the second, for selecting targets.

When a warhead, or a decoy, is travelling beyond the atmosphere, its motion is nearly totally determined by gravitation and can be computed fairly accurately if all the local gravity anomalies are known. It should be noted, however, that some military planners fear that because the polar trajectories have not been checked in practice, there is no guarantee that the accuracies achieved in the medium latitudes can be maintained in flights over the pole.

In the terminal phase the 'threat cloud' thins out, with the lighter decoys being retarded by atmospheric drag. A warhead completes the terminal phase relatively quickly—in a minute or so. The attacker can make his warheads manoeuvrable, and so the defender must keep tracking them continuously, which may pose problems to use of some types of weapons. Since the attacking side can program its warheads to explode if intercepted (salvage fuzing), a ballistic-missile defense must ensure that the warheads are destroyed at a rather high altitude (40–50 km). In this respect exoatmospheric weapons are preferable. Ground-based and air-based antimissile weapons are dominating the discussion on terminal-phase defense systems. They are local in nature, whereas boost and mid-course defenses must provide global coverage.

The features of the individual phases of the trajectory of a ballistic missile from the viewpoint of missile defense are summarized in Table 1.1.

The space-based ballistic-missile defense proposed in the SDI relies on the following directed-energy weapon concepts:

1. Laser weapons (chemical, excimer, and X-ray), which would deposit energy within a thin layer on a target.
2. Particle beams, which deposit energy deeper within the target.

3. Kinetic-energy weapons, i.e., ballistic and homing missiles and projectiles boosted to high velocities, all of which would destroy their targets by mechanical impact.
4. Electromagnetic-pulse weapons, which are similar in effect to the action of an electromagnetic pulse from a nuclear blast. These include microwave beams or high-current beams of charged particles.

Table 1.1 *Characteristics of the phases of an ICBM's trajectory*

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Boost phase	200 (can be reduced down to 50)	100–150 (can burn out in atmosphere)	Minimum	Fuel compartments	Space (completely or key elements)
Midcourse phase	1,000 (much shorter with depressed trajectories)	— (sometimes with depressed trajectories)	Maximum (increase by two orders of magnitude)	Threat cloud (or MIRV's if selected)	Space (or ground at the end)
Terminal phase	100	Completely	About minimum	MIRV's (dispersed)	Air or ground

The various forms of directed-energy weapons have been extensively written up in the US mass media within the first months of the announcement of the SDI program and were described as a step forward to the acquisition of a nationwide space-based BMD. Indeed some of the directed-energy weapons, which have become possible due to major advances in science and technology, stand apart in comparison with current arms in that they feature:

a. Nearly instantaneous kill, since they transfer energy at the fastest speed possible (with lasers) 300,000 km s^{-1}, or nearly so (with particle beams). So at a range of 3,000 km, say, these weapons can hit a target within 0.01 s. True, a target moving with a velocity of several kilometers per second will have moved by some tens of meters within that instant, but this can be taken into account because it is impossible to change the target's trajectory so quickly.
b. Gravity has essentially no influence on the trajectories of particle and laser beams. Relativistic (i.e., travelling at near-light speeds) particles will be moved by gravity from a straight line by a fraction of a millimeter over 3,000 km (for hydrogen atom beams). As for laser beams in the earth's gravitational field, not even the most sensitive of today's measuring devices would be able to detect a deviation.
c. Enormous kill radii, which are only limited by the divergence of beams and the difficulties of focusing them (a spot on a target grows in size with range).

Both advocates and critics of the SDI agree that directed-energy weapons can only be employed to their full potential when deployed in space.

We will now take a closer look at individual types of the above-mentioned weapons.

1.1 Laser weapons

As indicated above, laser weapons affect the surface layer of a target. They effectively destroy by thermal or impulse (with pulsed lasers) action thin-walled shells, such as the walls of fuel compartments, the sheet of airplanes and helicopters, oil and gas storages, and so on. It follows that lasers deployed in space can be used both against ballistic missiles in their boost phase and against ground-based targets.

The atmosphere is transparent to laser radiation with wavelengths between 0.3 and 1 μm, i.e., in a wider range than the visible part of the spectrum. For longer wavelengths, in the infrared, there also exist the so-called 'spectral windows' where there are no molecular absorption bands due to atmospheric constituents. The atmosphere is absolutely opaque to wavelengths shorter than 0.3 μm, including X-rays. But even a laser beam that can theoretically pass freely through the atmosphere is scattered by clouds, fog, aerosols and dust.

The damage to thin-walled shells can be estimated in a fairly simple way. To burn through an aluminum sheet with an effective thickness of 1 g cm^{-2} requires an energy deposition of about 1 kJ cm^{-2}. For magnesium alloys and the same effective thickness nearly the same amount of energy is required, and for titanium 50 per cent more (these materials are the most common ones for the walls of missile fuel compartments). The thermodynamic characteristics of these and some other materials are listed in Table 1.2.

Table 1.2 *The thermodynamic properties of some materials* [1.8]

Material	Melting point	Me[illegible]	[illegible]	[illegible]
Aluminum	660	1,060	2,500	12,000
Magnesium	650	1,090	1,095	6,000
Titanium	1,670	1,500	3,300	10,000
Uranium	1,130	200	1,200	2,250
Plutonium	640	125	3,350	1,430
Silicon	1,415	2,760	3,250	16,000
Carbon				59,250

The laser-matter interaction process is a fairly complex one, therefore we will confine ourselves to its simplified description. The bulk of the laser radiation is absorbed in a relatively thin surface layer within the material. How much is absorbed is controlled by the laser pulse duration and the material's thermal diffusivity. If the latter is high, then even short pulse durations will be enough to

heat a fairly thick surface layer of the material. If it is low, energy deposition for the most part occurs within the layer in which the pulse is absorbed. This layer may then melt, evaporate, or even become ionized, the rest of the material remaining cold. The behavior of the wall material is dictated by its thermal diffusivity $\varkappa$, which has dimensions $cm^2\ s^{-1}$. Using this parameter we can determine the time required for a layer of thickness Δ to heat up

$$t = \Delta^2/\varkappa.$$

One can also solve the inverse problem—to find the thickness of the heated layer given that the laser pulse is of length τ

$$\Delta = \sqrt{\varkappa\tau}.$$

The thermal diffusivities of the materials common in missile technology are given in Table 1.3. The value of $\varkappa$ depends on the density, heat capacity, and thermal conductivity of the material, i.e.,

$$\varkappa = \lambda/C_p\rho,$$

where ρ is the density, λ is the thermal conductivity, and C_p is the heat capacity.

Table 1.3 *Physical properties of some materials* [1.8, 1.9]

	[illegible]	[illegible]	[illegible]	[illegible]
Aluminum	2.7	0.9	2.0	0.83
Magnesium	1.74	1.0	1.0	0.57
Titanium	4.5	0.5	0.2	0.086
Copper	8.9	0.38	4.0	1.15
Carbon	2.25	0.71	1.0	0.625
Phenolformaldehyde resins	1.73	0.8	0.0016	0.0012
Carbon-filled plastics	0.59	1.6	0.001	0.001

The characteristic time T required for the entire shell to heat up is

$$T = d^2/\varkappa. \tag{1.4}$$

If $\tau \gg T$, then the heating occurs as described above. If $\tau \ll T$, then the interaction mechanism is that of impulse impact.

Let us consider a unidimensional problem, which corresponds to the incidence of a light beam on a plane. Let the radiation heat the layer of effective thickness δ ($g\ cm^{-2}$), and let the fluence of the incident beam Q ($J\ cm^{-2}$) be so

high that the energy deposition q (J g^{-1}) is much higher than the evaporation heat, so that we can well assume that the layer δ evaporates and the molecules heat up to a temperature that is characterized by the mean molecular velocity

$$v \propto (Q/\delta)^{1/2}.$$

The resultant gas layer imparts to the material the specific momentum

$$P \propto (Q\delta)^{1/2}.$$

As a result, the shell material is accelerated to the velocity

$$c \propto (Q\delta)^{1/2}/d,$$

where d is the effective thickness of the shell (g cm^{-2}).

For the material not to disintegrate the velocity must constitute a small fraction of the sound velocity in the shell material, i.e.,

$$c \propto \alpha c_{\text{sound}},$$

where $\alpha \sim 10^{-2}$.

Consider, by way of example, a pulsed laser with pulse duration 10^{-8} s. The thickness of the absorption zone can be estimated by the relation $\delta = (\varkappa\tau)^{1/2}$, which for aluminum gives 3×10^{-4} g cm^{-2}. The sound velocity in aluminum being 6 km s^{-1}, for an effective thickness of the shell of 1 g cm^{-2} we obtain the kill threshold of about 10 kJ cm^{-2}. The energy deposition q of the laser pulse can easily be verified to be much higher than the evaporation heat (12 kJ g^{-1} for aluminum), and so the assumption we made is valid.

If we put $\tau = 10^{-6}$ s, then the kill threshold will go down to 1 kJ cm^{-2}, but now the energy deposition will be close to the evaporation heat and we reach the limit of the applicability of our assumption.

Estimates show that the threshold for the impulse kill of a pulsed laser is not lower than that for a thermal kill.

The thermal kill threshold can be raised substantially by covering the shell with a layer of a substance having a sufficiently low thermal diffusivity (ablative coating). The incident energy is now absorbed in a thin coating layer, heats it up, and it evaporates leaving the shell intact. As can be seen in Table 1.3, an ablative coating of carbon-filled plastics has a thermal diffusivity three orders of magnitudes lower than that of aluminum, i.e., an ablative coating with an effective thickness of 0.5 g cm^{-2} (about 3 mm) can retain its protective properties for nearly a minute. The thickness of 0.5 g cm^{-2} is chosen because of weight constraints (our earlier assumption was 1 g cm^{-2} for shell thickness). Since the evaporation heat for carbon is about 60 kJ g^{-1} (see Table 1.2), this protective layer would survive energy depositions up to 30 kJ cm^{-2}. This, it seems, is the practical limit of protective capabilities of thermal insulation. Most US estimates assume a thermal kill threshold for laser weapons of about 20 kJ cm^{-2}. Similar values are quoted for the impulse kill of pulsed laser weapons.

We will thus proceed from the following kill threshold of a missile's fuel compartment for laser weapons:

$$Q \geqslant 20\,\mathrm{kJ\,cm^{-2}}.$$

As we noted above, there are physical constraints on the divergence of a laser beam, the minimal possible divergence being determined by the so-called diffraction limit

$$\theta \propto \lambda/D,$$

where λ is the wavelength of the laser radiation, and D is the diameter of the corresponding focusing mirror (in all the relations in this section all the near-unity factors are discarded).

When focusing the beam on a target what is obtained in the focal plane is not a point but a spot of diameter

$$d = (\lambda/D)R,$$

where R is the focal distance of the mirror system.

In terms of the efficiency of a laser weapon it is important that the spot on the target be as small as possible, i.e., the distance to the target must equal the focal distance. Defocusing increases the spot size:

$$d^2 = \left(\frac{\lambda}{D}R\right)^2 + \left(\frac{D}{R}\Delta R\right)^2,$$

where $\Delta R/R$ is the focusing factor.

If the spot on the target is sufficiently small, so is the 'depth of focus' (ΔR). Since it is unlikely that the focal distance can be changed from shot to shot, the real spot size will be larger than the theoretical minimum.

It is also important for the spot to be smaller than the effective diameter of the mirror, otherwise, the thermal load (or impulse impacts) on the mirror will be so high that the repeated use of the mirror would be out of the question [illegible]. If we substitute $d = D$ into formula (1.11), we obtain

$$D = (\lambda/D)R,$$

or

$$D^2 = \lambda R.$$

The latter expression defines the limiting kill radius for a laser of a given type and a mirror of a given size, the radius being independent of the laser power itself. The relationship of the three parameters (mirror diameter, laser wavelength, and kill radius) is illustrated in Figure 1.2.

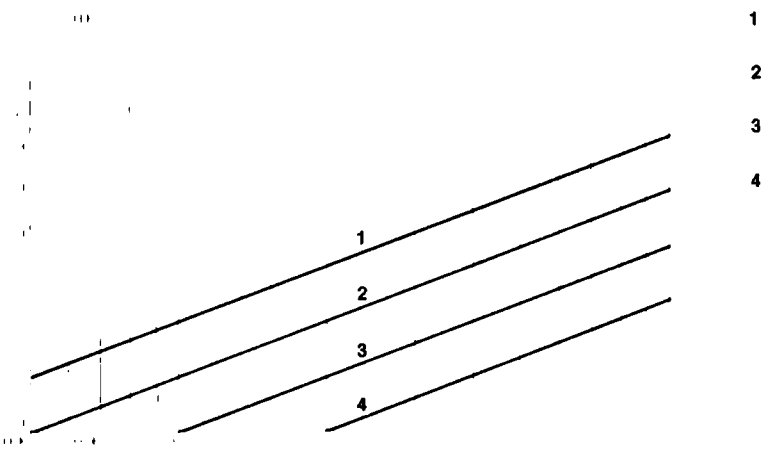
In the general case the kill radius is also dependent on the power of the radiation source. The energy fluence on the target is given by the formula

$$Q = W\tau/R^2\theta^2,$$

where W is the laser power, τ is the pulse duration, R is the range, and θ is the divergence angle of the laser beam. Put $Q = q_0$, where q_0 is the energy threshold of target kill. Then

$$q_0 = W\tau/\theta^2 R^2.$$

The parameter $B = (W\tau)/\theta^2$ is called the brightness and it is defined as the amount of energy released by a source within a steradian (sr). This is the main



energy characteristic of a laser source. We can rewrite equation (1.16) in terms of B to make it suitable for our further analysis

$$R = (B/q_0)^{1/2}. \tag{1.17}$$

Setting, as earlier, $q_0 = 2 \times 10^4$ J cm^{-2}, we can easily arrive at a numerical relationship between kill radius and brightness (see Table 1.4).

Table 1.4 *Kill radius vs brightness for a laser source*

Radius, km	Bright
500	5×10^{19}
1,000	2×10^{20}
3,000	2×10^{21}
10,000	2×10^{22}

As was noted in the Fletcher panel's report [illegible], the current continuous-wave chemical lasers can have brightnesses up to 10^{15} W sr^{-1}, which is many orders of magnitude less than required for an effective laser weapon.

It is to be reiterated that laser systems are especially effective against the fuel compartments of missiles. The shells of warheads are much harder and their thermal insulation is better because they are designed to survive the intensive heat of reentry. To get some indication of the required thermal protection for a warhead we now turn to the example of the probe on the Galileo mission. The probe was designed to descend in Jupiter's atmosphere, which is much denser than the earth's. It was calculated that the probe must sustain thermal loads of about 100 MJ cm^{-2} for about 100 s. Obviously, warheads must be designed to survive energy depositions from 10 kJ cm^{-2} to 100 MJ cm^{-2}.

For the sake of our analysis of the energetics of a laser system, we assume that the spot size must roughly correspond to the targeting accuracy. On the other hand, this accuracy must be commensurate with the target's dimensions. Higher accuracies require significantly more sophisticated aiming systems. The optimal spot size must thus be about that of the target. For present ICBM's the spot size is estimated to be about one meter.

The energy of a laser shot must therefore be 200 MJ, an equivalent of the energy released in a detonation of 50 kg of trinitrotoluene (TNT). The efficiency of lasers using atomic or molecular transitions is not very high—several per cent at best. The energy released within the source itself is so high that the active medium in which the lasing occurs disintegrates after the shot. This is to be taken into account when designing reusable sources.

Suppose now that hundreds of ICBM's were launched from a small launch site area simultaneously, then the space-based laser weapons will be confronted with this swarm of missiles. This imposes the following requirements on a battle station in space:

— defensive resources—up to 1,000 shots;
— firing rate—up to several tens of shots per second.

We have thus sketched some of the problems common for laser weapons of all types. These problems in turn lead to a host of technological issues that the designers of the laser weapons will have to face. We will now turn to the possible ways in which these defensive systems might be realized. In the American literature on the SDI only four types of laser are now being considered:

a. hydrogen fluoride (HF) chemical lasers;
b. excimer lasers;
c. nuclear-bomb-pumped X-ray lasers;
d. free-electron lasers.

1.1.1 HF chemical lasers

The research and development program for this laser is in especially advanced stages in the US. The laser is pumped by the chemical reaction between

hydrogen and fluorine:

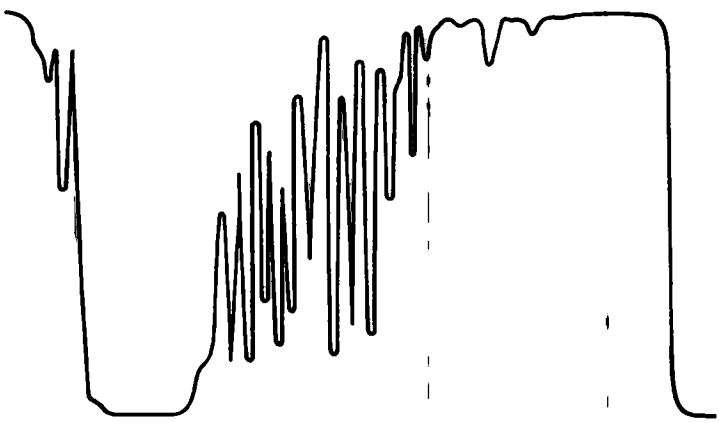
$$F + H_2 \rightarrow HF\,(\text{excited}) + H,$$

$$H + F_2 \rightarrow HF\,(\text{excited}) + F.$$

The reaction has been thoroughly studied, under normal conditions it is explosive. To suppress detonation and make it suitable for continuous-wave lasing, the mixture of fluorine and hydrogen is diluted with nitrogen or helium. This trick increases the mass of the mixture several fold since a 'dilution coefficient' is estimated to be about four[1.11,1.12].

The resultant HF molecules are in an excited state. Excited are the vibrational-rotational levels, which are about equally spaced in energy. The excitation degree, especially for the second reaction, is very high—up to the tenth level, although most of the radiation comes from transitions between lower levels. The HF laser is thus not a monochromatic source, and its emission spectrum contains many lines, which lie between 2.6 and 3.0 μm. The often-quoted wavelength of 2.8 μm of the HF laser corresponds to the middle of this interval.

It is worth noting that it is in this interval that the many of the absorption lines of water lie (Figure 1.3). Water vapor is unevenly distributed over altitude



with the major contribution to the optical thickness for the absorption of the laser beam coming from the troposphere (up to 10 km). Consequently, the beam of a space-based HF laser would be weakly absorbed in the upper atmosphere (20–30 km), but completely absorbed by the troposphere. In order that a laser beam might reach the ground without significant losses it is proposed that deuterium fluoride (DF) be used as the lasing medium. This laser radiates at 3.6–4.0 μm, a range to which the atmosphere is transparent.

One important technological characteristic of the chemical laser is its specific energy release—the amount of energy that can be released per unit mass of gas mixture. Let us estimate these quantities for hydrogen fluoride and deuterium fluoride.

We will take a DF laser at 3.8 μm, which corresponds to a photon energy of 0.33 eV (for the HF laser—2.8 μm and 0.44 eV, respectively). If we assume that the chemical reaction proceeds till the 'chemical fuel' has 'burned out' completely, i.e., each DF (or HF) molecule has contributed to the formation of laser radiation (each yielding only one photon), then a mole of lasing medium will yield

$$W = 0.33 \times 1.6 \times 10^{-19} \times 6 \times 10^{23} = 3.2 \times 10^4 \text{ J for DF}$$

and

$$W = 4.3 \times 10^4 \text{ J for HF.}$$

The molecular mass of DF being 21 (20 for HF), we obtain, after multiplying by the dilution coefficient, the specific energy release

$$q = 3.2 \times 10^4/(21 \times 4) = 380 \text{ J g}^{-1} \text{ for DF,}$$

$$q = 530 \text{ J g}^{-1} \text{ for HF.}$$

The first two assumptions (complete burn-out and no deactivation of the excited molecules) lead to an overestimation of the energy release; and the assumption of one photon per molecule, to an underestimation. It is difficult to assess how valid the first two assumptions are and this will be a subject of further studies. As regards the last assumption, in the limiting case the correction factor may be up to two.

It is of interest to provide earlier estimates for HF lasers. The Soviet Scientists' Committee for the Defense of Peace Against Nuclear Threat reported a figure of 100 J g^{-1}, the Union of Concerned Scientists (USA) think that it is 500 J g^{-1}, and in a study by the US Congressional Office of Technology Assessment the higher figure of 1,000 J g^{-1} is given. Lastly, in a Soviet book *Chemical Lasers* it is maintained that, depending on the operating conditions, the energy release may vary from 100 to 1,000 J g^{-1}.

A continuous-wave laser works on the principle of fast pumping of a working gas mixture through the resonator. In high-power lasers the gas must be pumped at supersonic speeds. The arrangement resembles a jet engine and is a source of strong vibrations, a totally unacceptable thing for space-based weapons. Today's HF lasers have powers of several megawatts. It will be recalled that the powers needed for space-based laser weapons are nearly three orders of magnitude higher. The gap can hardly be filled by improving the specific energy release or increasing the resonator volume, because it is unlikely that the optical homogeneity of the supersonic flow can be ensured over large cross-sections.

Therefore, it seems highly questionable at present whether the required powers could be generated in a single resonator. Of course, a bank of identical parallel blocks could be used. This bank would not be required to function in synchronism. What is only important is that they are aimed accurately enough at one target, i.e., that the beams converge on it. But this arrangement significantly increases the size of a continuous-wave laser space station.

The efficiency of an HF laser is low (several per cent), but the problem of heat removal is solved here automatically: by releasing the exhaust working medium into the surrounding space at supersonic speeds. Accordingly, during the operation of a combat laser station a cloud of gas will form around it consisting of the HF molecules in a normal state and diluent molecules.

The cloud will present two kinds of hindrances to the laser weapon. First, beam absorption by the surrounding gas ($0 \rightarrow 1$ transition); and second, disturbances in the aiming and tracking system due to turbulence and inhomogeneity of the environment. These hindrances will accumulate as the station operates and so they may drastically impair its combat efficiency.

Even so they may not be that formidable in reality. To begin with, HF laser radiation is not monochromatic. Even if a line corresponding to the transition from the first excited level to the ground level is absorbed and not reemitted, the total intensity will drop but insignificantly, since the other lines will not be absorbed by the surrounding gas. To answer the second question we will try and estimate the amount of gas that might happen to be on the line of sight.

To obtain rough estimates we will consider a simpler problem. Let a sphere of radius R emanate gas isotropically with the total yield w (g s^{-1}). The gas density at an arbitrary radius r will then be

$$n(r) = w/4\pi r^2 v,$$

where v is the expansion rate of the gas cloud.

From this we can readily find the mass of gas on the line of sight in terms of g cm^{-2}

$$\mu = \int_R^\infty n(r)\,dr = w/4\pi R v.$$

It now remains for us to choose realistic values of the parameters. Take a 2-GW laser. Let its minimal output be 100 J g^{-1}. Then $w = 2 \times 10^7$ g s^{-1}.

We now put $R = 5 \times 10^3$ cm (in view of the foregoing this seems quite reasonable) and $v = 10^5$ cm s^{-1}. Then

$$\mu = 2 \times 10^7/(4\pi \times 5 \times 10^3 \times 10^5) \simeq 3 \times 10^{-3}\,\mathrm{g\,cm^{-2}}.$$

This value of μ tells us nothing so far. Note only that it is much smaller than the

value obtained for the passage of the light beam through the earth's atmosphere (1,000 g cm^{-2}).

The assumption of the isotropic gas release is a simplification. With large releases any anisotropy in the gas stream would result in jet propulsion, which would shift and twist the battle station. Compensating for these effects will require much fuel, its amount being comparable with that of the working gas medium of the laser. These effects would thus cause appreciable disturbances for the stabilization system of the station.

1.1.2 Excimer lasers

These lasers now figure prominently in R&D plans. The active medium of the excimer laser is a chemical compound of an inert gas in unstable excited states. After the excitation has been removed (by emitting a photon) these compounds disintegrate. Excimer-producing reactions are initiated by external sources by heating up the gas mixture using an electron beam, an electric discharge in the gas mixture, or by the so-called 'nuclear pumping' (by using nuclear-reactor neutrons to produce in the working volume energetic ions, which then initiate the reactions required). It has also been discussed whether excimer laser can be pumped by a nuclear blast.

Excimer lasers are pulsed monochromatic devices. Excimer reactions have a high (up to 50 per cent) 'internal efficiency,' i.e., the ratio of energy in to energy out. The total efficiency of the system, including the efficiency of external energy input into the working volume, is much lower, of course. It is reported to be 5—6 per cent, although it can be improved to 10 per cent.

The excess energy is mainly consumed by gaseous component, which cannot be reused until it has cooled down. Although in moderately powerful industrial excimer lasers it is possible, using relatively simple techniques, to cool the working mixture and so to achieve a pulse repetition rate of nearly 1 kHz, in an SDI-oriented applications with their huge outputs, it is no longer possible to provide the firing rate required. This will perhaps call for block design of the system with each block actuated in succession. But this would markedly increase the overall size of the battle station in space.

Another feature of excimer lasers is that they radiate in the ultraviolet range to which, generally speaking, the atmosphere is opaque (or translucent). The following are the characteristic wavelengths of the halogenides of inert gases that can be used in excimer lasers:

a. argon fluoride ArF—1,930 Å;
b. krypton chloride KrCl—2,220 Å;
c. krypton fluoride KrF—2,480 Å;
d. xenon chloride XeCl—3,080 Å;
e. xenon fluoride XeF—3,510 Å.

Plus molecular xenon with wavelength 1,720 Å.

It is worth noting that excimer lasers are used as reference radiation sources in frequency multiplication processes. For example, the seventh harmonic of the KrF radiation at 355 Å has been successfully obtained. The efficiency of the process was as low as 10^{-5}, although there are prospects that it can be improved by two orders of magnitude.

We now wish to estimate the specific energy release in an excimer laser using the same approach as for chemical lasers—namely by assuming that the gas mixture has reacted completely, that the excitation of excimer molecules is removed only by emitting a laser photon (one photon per each emission act), and that the dilution coefficient is unity. For definiteness, we take two longer-wave excimer lasers (XeCl and XeF).

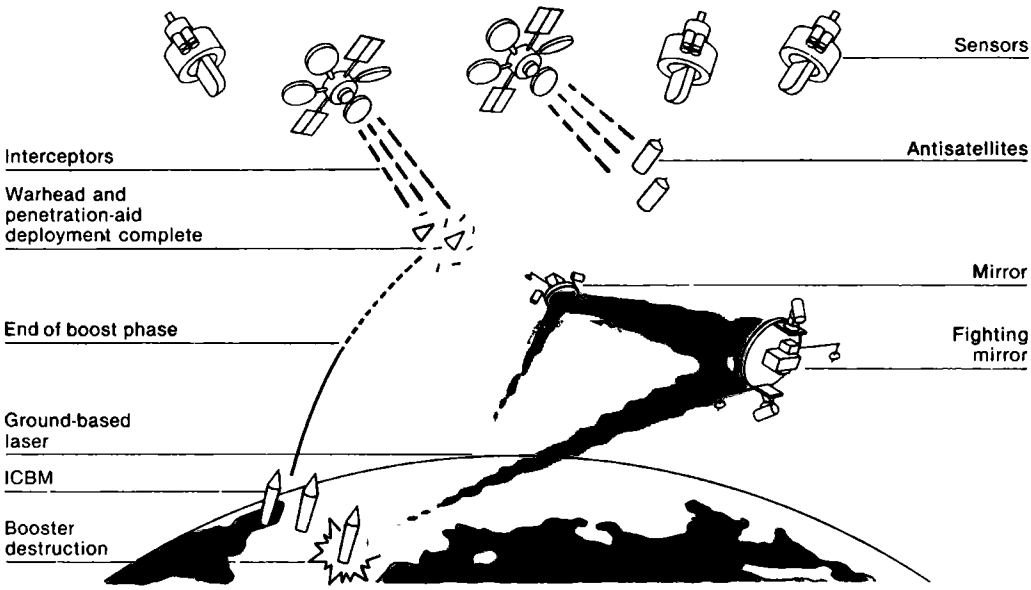


Fig.1.4 *One of the ver of an ICBM killing in the boost phase* [1.11]

For XeCl, wavelength 3,080 Å (for XeF 3,510 Å) corresponds to a photon energy of 4 eV (for XeF 3.5 eV). The molecular mass of XeCl is 167 (150 for XeF). It follows that the specific yield for XeCl is 2.4 kJ g^{-1}, and for XeF, 2.3 kJ g^{-1}. Note that these are upper bounds.

These wavelengths lie just at the boundary of the spectral window of the atmosphere. To guarantee free passage through the atmosphere it would be desirable slightly to increase the wavelength. This can be realized on the basis of the so-called stimulated, or induced, scattering. This occurs when radiation with frequency ω, on passing through a substance with characteristic molecular frequency ω_n, is transformed into radiation with frequency $\omega + n\omega_n$, where n is an integer. This process, naturally, involves energy losses, at any rate by half.

The above-mentioned outputs of excimer lasers are somewhat higher than those of the HF chemical lasers, although this is not true of the energetics of the laser station as a whole. Chemical lasers do not need any special power supplies for pumping, whereas excimer lasers with their low efficiencies do, and the issue of the power requirement for the pumping comes to the fore, running into hundreds of gigawatts with repetition rates of tens of hertzs.

It is quite obvious that these requirements cannot be met by space-based power supplies, whose capabilities are strictly limited by mass and overall size. Lifting into orbit of energy accumulators meeting the above power specification would increase the mass of the station unacceptably, since the mass equivalent of energy for accumulators is all too high—100 J g^{-1} for many accumulators is as yet a desirable, although remote, target figure.

For this reason excimer laser weapons deployed in space offer no promise. But ground-based excimer lasers are considered in the SDI plans to be promising components of the space-based ballistic-missile defense. Sophisticated aiming schemes have been proposed that use space-based mirrors, some of them even placed in geostationary orbits (Figure 1.4). This is possible in principle owing to the small wavelength of the excimer laser, and this would also increase the lethal range (for the same mirror dimensions) ten-fold as compared with the HF chemical laser.

1.1.3 Nuclear-bomb-pumped X-ray lasers

Some observers believe that one of the reasons behind President Reagan's March 23, 1983, speech on defense spending and defensive technology was the result of tests of an X-ray laser pumped by a nuclear blast. The possibility of induced transitions in quantum systems was shown by Einstein back in 1917. Starting off with purely thermodynamical considerations, without any relevance to specific systems, he derived a relationship between the coefficients of spontaneous (A) and induced (B) radiation:

$$A/B \propto \lambda^{-3}, \tag{1.24}$$

where λ is the wavelength of electromagnetic emission. It can be seen that the ratio grows rapidly as the wavelength falls. This accounts for the snags encountered by short-wave laser designers.

A closer examination shows that as the wavelength decreases the required pumping power goes up. For example, for $\lambda = 1$ Å the requirement is $10^{17}-10^{19}$ W cm^{-3}. It should be emphasized that the pumping energy varies like the fourth power of the wavelength. Therefore, for $\lambda = 10$ Å (1-keV quanta) the required input is much lower: $10^{13}-10^{15}$ W cm^{-3}.

But even these values are too high, and such conditions can only be realized in some 'exotic' cases, e.g., in a laser focus or a nuclear detonation. It was in these cases that it was possible to ensure the conditions necessary for X-ray lasing.

X-ray lasers are thus pulsed lasers with rather short pulses. With so high an input the active medium of the laser will be a plasma, and a strongly ionized plasma at that.

Some of the plausible realizations of an X-ray laser have long been getting a great deal of attention in the literature. To be more specific, we will take one form, the so-called recombination laser [1.13, 1.14].

Suppose the thermal radiation yield of a nuclear explosion (mostly X-rays with quanta of several keV) is sufficiently high to ionize fully a substance with atomic number z. Note that after the medium has been ionized fully it becomes transparent to X-rays, so that the substance will gradually be 'eaten up' if the passage time of the pulse front is long as compared with the ionization time.

After the explosion the fully ionized plasma begins to cool down (with no energy inputs except for the Compton scattering of nuclear-explosion photons by the electrons of the substance), the electrons cooling faster. When the electron temperature has fallen sufficiently, the recombination process sets in. First of all, the electrons begin to descend on energy levels of fully ionized atoms (hydrogen-like ions, so called because all the energy levels coincide completely with those of the hydrogen atom, which has been well studied both theoretically and experimentally, the only difference being that the energy scale differs by the factor z^2).

Calculations of the kinetics of these processes show that the energy level whose principal quantum number $n = 3$ will be depleted in electrons, with the result that induced transitions are possible to this level from those corresponding to $n = 4$ or 5.

For the $5 \rightarrow 3$ transition the energy of quanta emitted is

$$E_\gamma = 13.6 \times z^2(1/9 - 1/25)\,\text{eV} \simeq z^2\,\text{eV}. \tag{1.25}$$

To ionize fully a z-electron atom requires an energy of about three-four ionization potentials, i.e., about 40–50 z^2 eV. Accordingly, the efficiency of an X-ray laser of this type can only be several per cent, a typical value for atomic- and molecular-transition lasers.

The temperature of the pumping radiation must be higher than some figure, which is, generally speaking, proportional to z^2. It was shown that the density of electrons should not be too high to fulfil inverted population conditions. These conditions are met by atoms with z values close to 30 (e.g., iron, zinc, copper).

In 1981 an unofficial report was published [illegible] about an experiment on X-ray lasing during an underground nuclear detonation in Nevada, USA. The characteristics were reported to be: wavelength about 14 Å, pulse length more than 10^{-9} s, pulse energy about 100 kJ.

The evidence is still too scant for a meaningful detailed analysis. Note only that the $5 \rightarrow 3$ transition in zinc corresponds to a wavelength of 14.2 Å.

If the active medium started as a solid, then, during the short time of pumping (about 50 ns), its shape will change but slightly. The plasma produced will start expanding at about 50 km s^{-1}. If the initial radius of the rod (as will be seen later the active medium must have this shape) is a fraction of a millimeter, it will take 30 ns for conditions to establish that favour induced emission, which lasts for no longer than 1 ns. The real diameter of the active medium will then be about 1.5 mm.

It should be borne in mind that for wavelengths under 2,000 Å mirror optical systems fail and optical resonators can no longer be used to enhance, form, and focus laser radiation. X-ray lasers fall under this constraint. With them radiation is formed and focused by adequately choosing the geometry of active zone, since the beam convergence is governed by the ratio of transverse dimensions to longitudinal ones. Therefore, the best choice is a long slender cylindrical rod, or bar:

$$\theta \propto d/L, \tag{1.26}$$

where L is the rod length, and d its diameter.

The ratio L/d cannot, however, be made arbitrarily large. Here diffraction limits come upon the scene. They determine the minimal divergence

$$\theta^2 \propto (d/L^2) + (\lambda/d)^2, \tag{1.27}$$

where λ is the laser wavelength.

This reasoning reveals fundamental constraints on the angular divergence for a recombination X-ray laser: the effective diameter of the rod must be about 1 mm, implying that the real angular divergence for a 10-m rod will be about 10^{-4}. It follows that the brightness of the X-ray laser tested by the USA in 1981 must have been 10^{11}–10^{13} J sr^{-1} (for a rod of length 1–10 m)—still a long way from meeting the specifications. Note that the recommendations of the Fletcher panel indicate that the brightness of X-ray lasers must be raised over the next several years up to 10^{14} J sr^{-1}, i.e., the above estimates are fairly reasonable.

Kilovolt X-rays are strongly absorbed in all substances including air. For example, the effective mean free path of 14.6-Å radiation in nitrogen is about 2×10^{-4} g cm^{-2} (recall that the total effective thickness of the atmosphere is 1,000 g cm^{-2}). And so a kilovolt X-ray beam is absorbed in the upper atmosphere (higher than 100 km). True, if the laser beam is sufficiently powerful, it might 'drill' through the atmosphere. But this property of X-ray lasers is best exploited by firing not downwards from space but upwards from an altitude of 80–90 km from under a relatively thin atmospheric layer when the target is in space.

The X-ray beam has the same destruction mechanism as that of the pulsed lasers discussed earlier in the section. It is only to be noted that X-rays penetrate deeper into the material than follows from arguments in terms of thermal diffusivity. Appropriate figures for some of the typical structural materials are pro-

vided in Table 1.5. It is seen that the effective mean free path of X-rays is strongly de endent on the quantum energy and the nature of the material.

Table 1.5 *Effective mean free paths of X-rays in various materials in mg cm^{-2}* [1.16]

Material	X-ray photon energy, keV					Thickness of layer heated by 1-ns pulse
	0.85	1.04	1.25	1.49	1.73	
Magnesium	0.6	1.15	1.95	0.22	0.33	0.04
Aluminum	0.5	0.9	1.6	2.35	0.28	0.08
Titanium	0.1	1.16	0.28	0.44	0.67	0.04

We will now try to assess the potentialities of X-ray lasers from general considerations. To be sure, the form of the recombination laser considered above is not the only feasible alternative for ballistic-missile-defense applications. There are reports of laboratory experiments with a partially-ionized-selenium laser [1.17]. It has also been reported that in some underground laser tests at the Nevada Test Site the active medium was a material with large enough atomic number. But the assumption that the active medium is fully ionized does not militate the reasoning that follows.

The energy of a laser is determined by the number of fully ionized atoms in the active rod (in our rough calculations we ignore the losses):

$$W_0 = E_\gamma N \propto E_\gamma L d^2 n \propto E_\gamma L d^2 \frac{\rho}{A} N_{AB}, \tag{1.28}$$

where A is the atomic mass, and ρ the density of the rod material. Since the divergence angle is proportional to d/L (ignoring the expansion of the active medium), the brightness for one rod will be

$$B = \frac{W_0}{\theta^2} = W_0 \frac{L^2}{d^2} = E_\gamma N_{AB} \frac{\rho}{A} L^3 = qL^3, \tag{1.29}$$

where q is the density of the laser energy, as defined by

$$q = E_\gamma N_{AB} \frac{\rho}{A}. \tag{1.30}$$

Let $E_\gamma = 1$ keV $= 1.6 \times 10^{-16}$ J, and note that for almost all chemical elements ρ/A is about 0.1. Then

$$q = 0.1 \times 1.6 \times 10^{-16} \times 6 \times 10^{23} = 10^7 \text{ J cm}^{-3} = 10^{13} \text{ J m}^{-3}. \tag{1.31}$$

The rod length is not chosen in an arbitrary manner, it is dictated by the nuclear explosion yield Q, as it is imperative that even the rod's parts farthest from the blast center be fully ionized (recall that after the medium has been fully ionized it becomes transparent to an ionizing radiation).

Our further analysis requires a knowledge of the arrangement of the rods. Clearly, there are two limiting cases:

a. Strictly radial arrangement of rods.
b. Equidistant positioning of rods on the cylinder's generatrix, with the nuclear explosive on the axis (central line) (Figure 1.5).

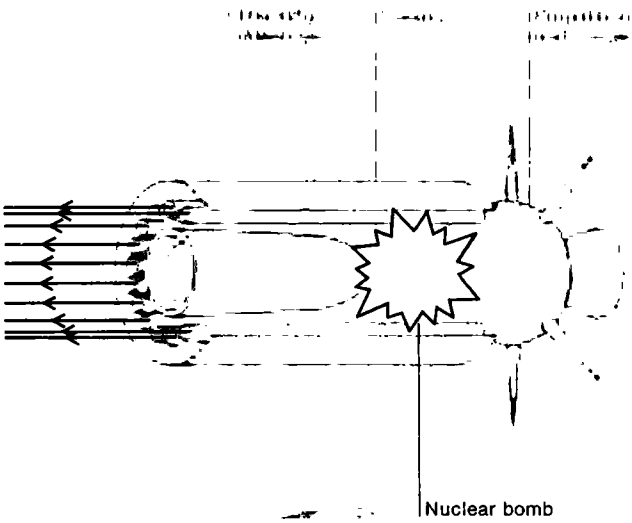


Fig. 1.5 Schematic of an X-ray laser [illegible]

It can be readily shown that case (a) is unattractive for energy considerations. In case (b) for simplicity we will consider that the distance from the explosion center to the end of the rod is equal to the rod's length. We now equate the amount of energy flowing through the rod to that required to ionize the entire rod:

$$q \frac{dL}{4\pi L^2} \simeq d^2 L \frac{q}{\varepsilon}. \qquad (1.32)$$

The total efficiency ε is composed of two factors, ε_1 and ε_2, where ε_1 is the share of the ionizing X-rays in the total electromagnetic spectrum of the nuclear detonation (normally it varies from 0.1 for a moderate explosion to close to unity for megaton explosion), and ε_2 is the laser efficiency, which for a recombination laser is about 2 per cent. Setting $d/L \sim 10^{-5}$ and $\varepsilon_1 = 0.3$ gives

$$Q_0 \simeq B/50. \qquad (1.33)$$

If the rod is 10 m long, its brightness is 10^{16} J sr^{-1}. It follows from (1.33) that to have a lethal range of 2,000 km (brightness 10^{21} J sr^{-1}) a 50-kiloton* nuclear yield and 10^5 rods are required. If we put $d/L = 10^{-4}$, as we did earlier for the recombination laser, then the requisite explosion yield will increase by a factor of 10, the number of rods remaining the same.

* 1 kiloton = 4 × 10^{12} J.—*Eds*

The kill range of an X-ray laser can be found from the formula

$$R = (B/q_0)^{1/2} = \left\{\frac{\varepsilon Q_0 N}{4\pi q_0}\frac{L}{d}\right\}^{1/2}, \tag{1.34}$$

where B is given by the relationship (1.33), N is the number of rods directed at one target, and q_0 an energy threshold of target destruction. For $Q < Q_0$ the laser does not function, and for $Q > Q_0$ its radius is no longer dependent on Q.

It should be noted that formula (1.34) is equivalent to that provided in the first report of the Soviet Scientists' Committee for the Defense of Peace Against Nuclear Threat [1.2] with $N = 1$ and Q_t substituted for Q_0.

All the lasers just discussed have one thing in common: they are all based on bound electrons, i.e., on transitions in closed quantum systems (atoms and molecules).

1.1.4 Free-electron lasers

In principle a beam of monoenergetic electrons is a kind of anomaly from the viewpoint of equilibrium distribution in phase space and it therefore has some features of inverted population.

Aperiodic deviations of an electron beam result in an emission of a limited number of photons (e.g., bremsstrahlung), which at the same time show no coherence. Synchrotron radiation behaves in a similar way in a magnetic field.

To achieve lasing a physical mechanism is required that would force the electrons in the beam to oscillate transversely with a preset frequency. This mechanism is provided by passing the beam through a set of magnets, or wiggler. The wiggler produces a time-independent magnetic field that varies in magnitude and direction. The fundamental wavelength of the induced electron radiation is determined by the formula

$$\lambda_0 = \frac{a_w}{2\gamma^2}\left[1 + \left(\frac{eHa_w}{2\pi mc^2}\right)^2\right], \tag{1.35}$$

where a_w is the wiggler period, H is the wiggler magnetic field, γ is the relativistic factor, equal to E/mc^2, E is the electron energy, and m is the rest mass of the electron. By the way, $mc^2 = 0.5$ MeV.

For the induced radiation to be initiated it is required that the following two conditions hold:

1. The wiggler must be sufficiently long (or be placed within the resonator to improve the effective gain).
2. The electron beam must be intense and as monochromatic as possible.

Free-electron lasers can function as (a) power amplifiers, (b) generators, and (c) frequency multipliers.

Operating as a power amplifier the laser produces induced radiation when a laser beam with wavelength λ_0 is sent through the wiggler along the electron

beam. The intensities of the two beams must be above some threshold level, the output power being dictated by the parameters of the electron beam. In this case it is desirable to employ a resonator.

When used as a generator, the system does not need an external laser: effects caused by fluctuations of the electron beam's density are amplified gradually. Of especial interest in this context is the so-called 'superradiance' condition, when a large gain is achieved and a substantial power is released in one passage of the beam through the wiggler. But after the passage the electron beam may deteriorate to such an extent that its further employment in the laser scheme may be no longer possible. The recuperation of the exhaust beam energy to be used to accelerate the next cluster of electrons presents no technological problems. And this would improve the total efficiency of the system.

When used as frequency multiplier the laser relies on the well-known relativistic effect of frequency multiplication in the scattering of light in the oppositely directed light and electron beams. In the process the wavelength shortens $4\gamma^2$ times. Induced emission can be caused without any auxilliaries (such as a wiggler) provided some conditions are met in relation to intensities and some other characteristics of both beams.

Returning to formula (1.35), we can see that the most significant contribution to the wavelength reduction comes from the factor γ^2 (it is hardly possible to make the wiggler period a_w less than one centimeter, normally it is several centimeters). In practice the electron energy can vary widely, thus enabling free-electron lasers to be made with an extremely wide and easily variable wavelength range (up to hard X-rays). It is these circumstances that make free-electron lasers so promising.

It is worth noting, however, that the practical development of these lasers is well behind the fundamental studies. Current experiments mostly focus on low-energy electrons, for which it is fairly easy to construct accelerators with adequate beams. Existing electron accelerators (especially the high-energy ones with $\gamma \geqslant 100$) are, as a rule, meant for other tasks, and they cannot always provide conditions required for free-electron lasing.

It appears that the best candidates for these lasers are linear accelerators, notably the high-current induction linear accelerators with γ of the order of 100. Specifically, such installations are available at the Lawrence Livermore National Laboratory and the Los Alamos National Laboratory (USA) actively involved in SDI studies.

The divergence angle of a free-electron laser is determined by the optical systems used. When the laser wavelength is too small for optics, the angle is proportional to $\{1/\gamma^2 + (\lambda/d)^2\}^{1/2}$, where d is the diameter of the electron beam.

The efficiency so far achieved for free-electron lasers is only a few per cent and their output power is rather small. At present it seems unlikely that an electron accelerator with an appropriate power supply can be deployed in space. In

other words, free-electron lasers, even if they reach a level commensurate with SDI requirements, will most likely be based on the ground, just like excimer lasers.

Free-electron lasers are quasi-continuous devices. The most suitable working wavelength seems to be 0.5–0.6μm—right in the middle of a spectral window.

The most important characteristics of the laser types we considered above (in terms of the SDI) are provided in Table 1.6.

Table 1.6 *Characteristics of the lasers*

Laser type	Wavelength	Passage through atmosphere	Energy source	Basing	Weapon class	Mass characteristics
Chemical-HF	2.8 μm*	No	Internal	Space	Space-to-space	2 t fuel per shot
Chemical-DF	3.8 μm*	Yes	Internal	Space	Space-to-space Space-to-ground	2 t fuel per shot
Excimer	0.2–0.3 μm	Yes**	External	Ground + space mirrors	Ground-to-space Ground-to-ground (?)	
X-ray	10 Å	No	Nuclear explosion	Space (pop-up)	Space-to-space	The lightest among the types in question
Free-electron	Any	Can be provided	External	Space (?), or ground + space mirrors	Space-to-space (?) Space-to-ground (?) Ground-to-ground (?) Ground-to-space	

Notes. * Nonmonochromatic.
** Working wavelength must be changed

1.2 Particle-beam weapons

Beams of energetic particles may have either surface or volume destructive capabilities, depending on particle type and energy. Lower-energy particles are absorbed in a thin surface layer of a target, just like a laser beam (thermal or impulse effects). The penetration depth increases with particle energy. Particles ionize the atoms of the target giving rise to all manner of radiation effects. These effects are generally characterized by the amount of energy absorbed in a unit volume (or in a unit mass) of the material. This is a radiological approach.

Absorbed energy is normally measured in rads. The rad corresponds to 100 ergs of energy absorbed in a gram of matter. The often-used derivative is the megarad, which corresponds to 10 joules absorbed in a gram of matter.

It is generally believed that the main damage inflicted by an ionizing radiation in a material is through the radiation damage, to which semiconductor-based

electronics are especially sensitive (even at moderate doses). Most semiconductors are sensitive to megarad levels of radiation, though modern gallium arsenide semiconductor devices are an order of magnitude more hardened. Doses of tens of megarads are close to the thermal destruction threshold of some structural elements of space-based defense components. Interestingly, these doses are about the melting heats of uranium and plutonium, the major nuclear explosives (see Table 1.2).

In some cases the lethal threshold of a particle-beam weapon can be expressed in terms of the density of the particle current, which is more convenient from the technological point of view than megarads. In particular, such an approach is possible when dealing with the interaction of relativistic heavy particles (e.g., protons) with matter. It will be recalled that relativistic protons have large effective mean free paths in matter (hundreds of g cm^{-2}) with nearly uniform energy release along most of the path.

In fact, if we multiply the specific loss of energy (dE/dx) by the protons, expressed in terms of MeV/(g cm^{-2}), by the current density j (A cm^{-2}) and the pulse duration τ (s), the product will have the dimensions MJ g^{-1}. This product is the amount of energy deposited in a gram of target material. Accordingly, using the equation

$$W_D = (dE/dx)j\tau, \tag{1.36}$$

we can relate the dose of the absorbed energy to the current density of the ionizing particles. Quantity (dE/dx) normally has a fairly strong dependence on the particle energy, but for relativistic protons it is a constant and equal to 2 MeV g^{-1} cm^2. Hence,

$$j = \frac{W_D}{2 \times 10^6 \tau} \text{ A cm}^{-2}. \tag{1.37}$$

Consider the case when $W_D = 200$ J g^{-1} (melting of uranium and plutonium), and the pulse length is $\tau = 1$ s. The current density will then be $j = 10^{-4}$ A cm^{-2}. If, as in the case of the above-mentioned lasers, we wish to have a spot one meter across on the target, then the total proton current will be 1 ampere.

It has been mentioned several times that electron and proton beams only propagate without losses in a vacuum, e.g., above the atmosphere, at altitudes higher than 200 km. A specific feature of these beams is that they are charged, and so subjected to the influence of internal (electrostatic repulsion) and external factors. Neutralizing the space charge alone does not yield the desired effect—because of the ordered motion the beam will still behave like an electric current and will interact with the geomagnetic field, which is itself unstable and subject to random fluctuations.

An apparent answer is to neutralize not only the charge but the motion as well. To this end, electron and proton beams must have the same velocity and the same density, so that the symmetry remains throughout the flight from source to target.

Appropriate experiments have been performed with lengths of the order of meters in studies of the so-called 'electron cooling' of proton beams in charged-particle storage rings. In all probability, with larger dimensions the typical plasma instabilities will tell, disturbing the required symmetry and uniformity of the system, and rendering it vulnerable again to external actions.

More stable results can be achieved by using charge-exchange processes, which are well known in experimental physics, to produce a beam of fast hydrogen atoms. Attempts to make it directly, by attaching an electron to a fast proton, failed. One way out is to form high currents of negative-hydrogen ions and then to remove the extra electron from each ion by passing the beam through a special-purpose gas target. The efficiency of the charge-exchange process is close to 100 per cent.

High H^--ion currents have been obtained in some controlled fusion research programs where now H^--ion current sources are employed that produce hundreds of amperes. However, these sources are not suitable as injectors for the accelerators. In the meson factory at Los Alamos H^- ions are accelerated to energies of several hundred MeV with a mean current of a fraction of milliampere. Also at Los Alamos is being developed a special-purpose linear accelerator with H^--ion energies up to 50 MeV and mean currents of up to 0.1 A [illegible]. Moreover, there are some American H^--ion sources producing several amperes under an essentially continuous regime[illegible]. Proton injection into accelerators using H^- ions and neutral-hydrogen atoms has been studied at the Nuclear Physics Institute, Novosibirsk, USSR.

H^0 atoms travelling at near-light speeds are a fairly weakly bound system. The atoms easily lose their electrons, for example, when scattered by the residual gas in the upper atmosphere. The atoms will thus turn into protons, which are sensitive to the geomagnetic field. For this reason neutral-hydrogen beams are only effective at altitudes above 200–250 kilometers. This also suggests a countermeasure against H^0 beams—a gas shield.

As regards the lethal range for H^0 beams (which interact with a target like protons of the same energy), it should be noted that there is no diffraction limit such as affects lasers, since the effective wavelength of H^0 atoms (the so-called Compton wavelength) is of the order of 10^{-11} cm. The beam convergence angle is influenced by other two factors, however. First of all, the H beam at the accelerator output has finite linear and angular dimensions, or, as physicists put it, a finite phase volume (the product of the linear and the angular dimensions). According to the laws of physics, the phase volume (also called emittance in accelerator jargon) remains unchanged as the beam is further transformed by electromagnetic optics methods.

If the beam expanded to r, then the corresponding angular divergence will be X/r, where X is the accelerator's emittance. At a distance R the effective diameter of the beam is

$$d^2 = r^2 + (X/r)^2 R^2. \tag{1.38}$$

It can be easily verified that this expression has a minimum at

$$r^2 = XR. \tag{1.39}$$

The optimal value of d is thus given by

$$d^2 = 2XR, \tag{1.40}$$

i.e., optimal adjustment enables the beam's convergence caused by the emittance to be reduced.

As the H^0 atoms are formed, another sort of divergence makes itself felt. It is related to quantum effects in the transfer of momentum to the electron in the charge-exchange process. This divergence component was estimated to be

$$\alpha_H \simeq 2 \times 10^{-6} (E/500)^{-1/2} \text{rad}, \tag{1.41}$$

where E is the energy of H^- ions in MeV. Thus, the spot size for the H^0 beam on the target will be

$$d^2 = 2XR + \alpha_H^2 R^2. \tag{1.42}$$

Setting, as above, $d = 1$ m, we can use this formula to assess the kill range of a particle-beam weapon. But, to begin with, we will have to estimate the required particle energy.

We will consider that the main task of the beam weapon is to destroy the fissionable ignitor of the warhead. The critical mass of a uranium sphere with a reflector is 15–20 kg, i.e., the sphere has a radius of about 6 cm (the densities of uranium and plutonium are close to 20 g cm^{-3}). It is only sufficient to melt part of the fissionable ignitor, therefore the effective free path of protons must be about 100 g cm^{-2}. This corresponds to a proton energy of about 300 MeV.

It is also necessary to assess the emittance. The value quoted for the high-current proton accelerator at Los Alamos is $X = 10^{-6}$ m rad. Substituting $2 \times 10^{-6} R = y$ into (1.42) we obtain

$$d^2 = y + 5y^2/3, \tag{1.43}$$

where d is expressed in meters, and $y = 1$ corresponds to a range of 500 km.

If we put $d = 1$ m, then the kill radius will be somewhat larger than 250 km; $d = 1.6$ m corresponds to a radius of 500 km, and $d = 3$ m to 1,000 km. Since, as we have shown above, the needed current density is 10^{-4} A cm^{-2}, in the first case the total current must be 1 A, in the second about 3 A, in the third about 9 A, the corresponding beam power being 300, 900, and 2,700 MW, respectively.

It is normally believed that increasing the accelerator current impairs its emittance. If we set $X = 10^{-5}$ m rad, it will turn out then that the beam becomes one meter in diameter even at 50 km, and with a kill radius of 1,000 km (the spot will be over 5 m across) a beam current of nearly 30 A will require.

The above estimates indicate that the beam weapons are only suitable for relatively small kill radii (not larger than 1,000 km).

In terms of energy, today's accelerators feature a relatively high efficiency, so that it makes sense to speak about efficiencies of tens of per cent for future accelerators. On the other hand, particle-beam weapons are especially suitable for midcourse defense components. Since this phase lasts about 1,000 s, and the needed powers, as we have seen above, are of the order of gigawatts, then the total energy resource at an accelerator battle station must be about 10^{12} J (the equivalent of a quarter of a kiloton of TNT).

Note also that 300-MeV H^0 atoms travel at 65 per cent of the velocity of light, which leaves the 'instant kill' assumption valid.

We now want to determine the current needed to evaporate a small projectile, attacking a battle station, by a particle beam. This can be done from the following considerations. The required energy deposition (dose) can be found from tables like Table 1.2 (evaporation heats of typical structural materials are in the region of several tens of kilojoules per gram). The particle energy should be chosen in such a way that the paths of protons corresponded to the projectile size—for an effective thickness of 10 g cm^{-2} the energy must be 100 MeV, for 1 g cm^{-2} about 30 MeV. Then, it is necessary to determine the average values of energy deposition (for the above examples the values are 10 and 30 MeV g^{-1} cm^2). Finally, using formula (1.40) we find the values of $j\tau$: for a dose of 10 kJ g^{-1} we obtain for the two examples 10^{-3} and 3×10^{-4} A s cm^{-2}.

The particle beam has substantial momentum which may turn out to be sufficient to change the velocity of the incoming projectile.

In fact at 1 A cm^{-2} the proton flux is $6 \times 10^{18}\,(c/v)$ cm^{-2} s^{-1}, where v is the particle velocity, and c is the velocity of light. Then, the proton mass being 1.6×10^{-24} g, we determine the beam pressure:

$$P = 6 \times 10^{18}(c/v) \times 1.6 \times 10^{-24} \times vj = 3 \times 10^5 j \,\mathrm{dyn\,cm^{-2}}. \tag{1.44}$$

If the effective thickness of the projectile's skin is m g cm^{-2}, and the dwell time of the weapon is τ s, then the projectile's velocity will change by

$$\Delta v = 3 \times 10^5 j\tau/m \,\mathrm{cm\,s^{-1}}. \tag{1.45}$$

If we substitute the values of $j\tau$, obtained earlier in the section from the evaporation condition, we see that the projectile will evaporate before its velocity will have changed significantly (in the above example for $m = 10$ g cm^{-2} $\Delta v = 0.3$ m s^{-1}, and for $m = 1$ g cm^{-2} $\Delta v = 1$ m s^{-1}).

These examples illustrate that particle-beam systems possess a certain potential as weapons against kinetic-energy projectiles at relatively short ranges.

1.3 Kinetic-energy weapons

Kinetic-energy weapons are interceptor missiles launched against the space-based components of the opponent's defensive system to kill them by mechanical destruction. It would be sufficient for the relative velocity of the projectile and target to be of the order of kilometers per second, since for an effective thickness of the projectile skin of several grams per square centimeters the specific momentum deposited on the target surface will be as high as 10^5–10^6 g cm^{-1} s^{-1}. This is an order of magnitude higher than the destruction thresholds we found earlier when dealing with impulse action of lasers on thin-walled shells. The velocities of space-based objects are generally of the order of 8 km s^{-1}, so that speed needed for destruction can be easily achieved by just choosing the right collision geometry.

A target can be destroyed not only when directly hit by a projectile (the purely kinetic-energy concept). It can also be killed by exploding a missile in the vicinity of the target. In the latter case, the missile is fitted with an explosive device that goes off either automatically when it is close to the target or on command.

In the American military literature kinetic-energy weapons are classed as follows:

1. Ballistic projectiles moving by inertia in the endoatmosphere and only subject to the earth's gravitational field (including its inhomogeneities, which may be unknown).
2. Homing projectiles that can be used both in the atmosphere and beyond it. These are not designed to hit the target but are instead armed with a high-explosive or fragmentation (shrapnel) warhead (specifically, space mines can be viewed as a limiting case of this type of projectile).
3. Homing interceptors designed to collide with the target.

The earlier US Safeguard and Sentinel ABM systems belonged to the second type of ground-based fast-boost interceptors armed with nuclear warheads. They were meant as interceptors of attacking ballistic missiles in the terminal phase of their trajectory.

The American strategic planners seem to regard kinetic-energy weapons as the main (if not the only) type of antimissile terminal-phase defensive systems. This seems to account for the high proportion of the SDI budget that has been allocated to the development of these systems (about 25 per cent).

The technological advances since the days of Safeguard and Sentinel enabled homing and tracking systems to be improved substantially. Now the Homing Overlay Experiment program is under way: antisatellite weapon has been tested. It is essentially an interceptor launched from an F15 fighter aircraft. This weapon falls into the third category. Nevertheless, second-type interceptors—nuclear interceptors—will for a time constitute an integral part of terminal-phase defense systems (for example, against warheads capable of manoeuvring in the atmosphere).

Let us now look at the capabilities and features of kinetic-energy weapons used as components of the boost-phase and midcourse defense systems. In boost phase, it seems, the main candidates would be the weapons belonging to the third type, with guidance systems using infrared sensors to home in on the rocket plumes. The other types of kinetic-energy weapons appear to be less suitable for boost-phase defense. So, ballistic projectiles would not do because the attacking side can vary the velocity of an attacking ballistic missile in an unpredictable manner. Crudely guided (second type) projectiles would have to carry heavy warheads, which would impair their mass characteristics.

Remember that an attacking missile covers the boost phase of its trajectory in a relatively short time (about 100 s). Therefore, an important characteristic of an interceptor, which is the major determinant of its kill radius, is its velocity relative to the battle station:

$$R = vT,$$

where T is the time from launch to kill.

It should be noted that this time is, generally speaking, shorter than the burn-out time. To begin with, the interceptor has to accelerate to its final velocity, and so $t_{accel}/2$ must be subtracted from the initial time. But there is a further snag. The launch site may be covered by clouds (natural or artificial). A launched missile can only be detected with confidence when it has reached an altitude of about 10 km (above the clouds). It can be shown that a missile will reach the altitude 10 km (1/10–1/15 of the boost-phase altitude) in 20–30 per cent of the burn-out time.

Suppose that the time allowed for a kinetic-energy weapon is 100 s, then the final velocity of the interceptor must be about 10 km s^{-1} if we want to provide a kill radius of 1,000 km, a range comparable with that of other space-based weapons. The minimal acceptable speed is 3–4 km s^{-1}, which enables the interceptor to reach the top of the atmosphere from 400-km altitude. Once it enters the atmosphere the interceptor slows down; moreover, because of aerodynamic heating of the interceptor's skin the probability for its infrared sensors' redouts becomes high.

Turning to midcourse, note that it is the longest phase: warheads and decoys cover it in about 1,000 s—an order of magnitude longer than the boost phase. What is more, they travel in ballistic trajectories, which enables the defense to predict with sufficient accuracy their position, and so to hope that kinetic-energy weapons of the first type (unguided projectiles) can be used fairly effectively, provided their initial targeting is carried out adequately.

It might appear that the long duration of the midcourse flight of an attacking missile would allow interceptors with a lower velocity than in boost phase. This would make it possible to use lighter interceptors missiles and to have many more weapons on a battle station than could be accommodated on a boost-

phase intercept space-station of the same mass, an important advantage since in midcourse the number of targets increases significantly.

It is planned to station midcourse BMD components at an altitude of 1,000 km. This would pose the problem of intercepting in a fairly short time (100 s) a threat cloud in a depressed trajectory (200–300 km). In that case, too, the interceptors would have to travel at about 10 km s^{-1}. This implies that a battle station would have to have some interceptors with that final velocity.

The typical situations just described show that the main problem with kinetic-energy weapons is to provide them velocities of about 10 km s^{-1} or more. For homing projectiles masses of several kilograms are sufficient (with current projectiles it is up to 15 kg). It is to be noted that a 1-kg projectile moving at 10 km s^{-1} has a kinetic energy of 50 MJ. It follows that the energy of a kinetic-energy weapon is comparable with those of the laser and particle-beam weapons discussed above. It appears that about 100 MJ per shot is a fairly universal characteristic in assessments of all kinds of space-based directed-energy weapons.

Of the many ways of accelerating bodies to high velocities we note the following three:

— gun firing (acceleration by expanding cordite gases);
— rocket-boosting (acceleration by a jet propulsion caused by burning fuel);
— electromagnetic (acceleration by magnetic or electric fields).

In artillery guns the limiting velocity is, in the final analysis, conditioned by the molecular velocity of cordite gases, it is 3 km s^{-1} or so.

Space-based gun systems face with the problem of compensating for the recoil, which will require extra fuel to orient and stabilize the battle station. This may also limit the firing rate of the station.

Since the outfly velocity of gun projectiles is relatively low and cordite is rather efficient fuel (for solid fuels the specific energy release is about 4 kJ g^{-1}), the requisite mass of the fuel is relatively low.

The parameters of the rocket-boosting of projectiles can be obtained from the Tsiolkovsky formula

$$v = v_0 \ln (M/m), \tag{1.47}$$

where v is the final velocity of a payload m, M is the initial interceptor's mass ($M \gg m$), and v_0 is the velocity of exhaust gases. For liquid fuels this velocity is 4.5 km s^{-1}, but liquid fuel components are thought of as poor storables for space-based weapons. And so US planners discuss only solid-fuel rockets, for which the exhaust velocity is 2.5–3.0 km s^{-1}.

The burn-out time depends on the engine thrust and the mass of the interceptor, and it normally varies from 10 to 100 s.

Let us now turn to the energetic efficiency of an interceptor rocket. The projectile's kinetic energy is $mv^2/2$, and the total energy expenditure is $Mv_0^2/2$. The energetic efficiency will be mv^2/Mv_0^2. Writing v/v_0 as y, then from the

Tsiolkovsky formula we have $m/M = e^{-y}$. The energetic efficiency will thus be

$$\eta = y^2 e^{-y}. \tag{1.48}$$

Table 1.7 tabulates the η vs y variation.

Table 1.7 *The function* $\eta = y^2 e^{-y}$

2	4	0.135	0.54
3	9	0.05	0.45
4	16	0.18	0.29
5	25	0.0067	0.165
6	36	0.0025	0.09
7	49	0.0009	0.044

A reasonable estimate of the final rocket-boosting speed is $6v_0$ (i.e., 15–18 km s^{-1}), because the efficiency of a similar acceleration method—electromagnetic—is also about 10 per cent, but it is independent of the projectile's velocity.

Whereas a projectile is only acted upon in guns for a limited time, in electromagnetic systems, which rely on the pressure of a magnetic field, it can be affected for longer. That is why electromagnetic system are getting so much attention now.

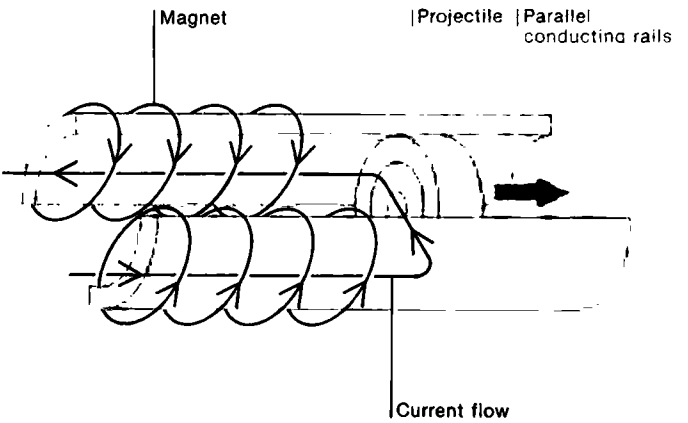


Fig. 1.6 *Electromagnetic gun* [1.25].

The most elementary example of electromagnetic accelerating system is the so-called 'rail gun,' a device well known to experimental physicists for decades [1.20]

The principle behind the rail gun is fairly simple (Figure 1.6). A voltage is applied to two parallel, or co-axial, current-carrying buses, or rails. If the circuit is completed by placing a conducting movable bogey on the rails, the current

flowing through the circuit generates a magnetic field. This field in turn generates a pressure $P = H^2/8\pi$, which tends to push the conductors aside. The massive rails are fixed, and so the only movable element is the bogey, which will start moving under pressure along the rails so that the volume occupied by the magnetic field grows, i.e., away from the power supply. The bogey will continue accelerating so long as the magnetic pressure is 'on'. The limiting velocity to which the bogey can be accelerated is

$$v^2 = 2aS, \tag{1.49}$$

where S is the speed-up distance, and a is the effective acceleration. To assess a we will need to know the magnetic field pressure. Suppose $H = 10^5$ G, then $P = 4 \times 10^8$ dyn cm^{-2} = 400 atmospheres. Suppose then that the effective thickness of the bogey is 10 g cm^{-2}, then the acceleration will be 4×10^5 m s^{-2} or $4 \times 10^4 g$. Under these conditions a velocity of 10 km s^{-1} will be attained within 125 m and 20 km s^{-1} within 500 m. If we start with the limiting values quoted as target figures in the report of the Fletcher panel, namely acceleration $10^5 g$ and velocity 20 km s^{-1}, the corresponding run will be 200 m. These figures are typical of electromagnetic accelerators. The on-rail time is v/a, and for typical values of the accelerator parameters this is hundredths of a second. Note, by the way, that these figures are all independent of the bogey's total mass, which only affects the total energy requirement.

The main objective of the rail-gun program is to achieve higher final velocities. It is not really possible to increase the linear dimensions to a kilometer or so. Higher accelerations are achievable either by using higher magnetic pressures or smaller effective projectile's thicknesses.

The magnetic pressure cannot be increased without limit—at pressures of about 1,000 atmospheres (i.e., 150–160 kG) the structure reaches the threshold of its mechanical strength. This structure, which is subject to huge internal pressures, would be exceedingly hard to make rigid and strong. Whereas attempts can be made to provide the required mechanical strength by making the rails themselves and auxiliaries more massive (which is undesirable because it increases the deadweight to be mounted in orbit), no amount of robustization would help against the loss of thermal stability.

If the current pulse duration is hundredths of a second, the skin-layer in copper is about one centimeter. Given a 120-kG field, the current density will be 100 kA cm^{-2}, and the thermal losses in the material about 400 J cm^{-3} (copper heats up to 120 °C) for 20-ms current pulses, the energy density of the magnetic field being 60 J cm^{-3}. Calculations show that the Joulean losses are close to the total energy stored in the magnetic field, the latter being exactly equal to the kinetic energy of the projectile. The efficiency of the rail gun is thus 33 per cent. If now we take into consideration that the efficiency of the power supply is not higher than 30 per cent, the total efficiency will be about 10 per cent, as noted above.

The heating would limit the firing rate of the system and any thermal damage would impair the reproducibility of shot characteristics.

Mass requirements seem to be in conflict with the desirability of having homing interceptors, whose mass cannot be reduced indefinitely.

Another consequence of huge currents is that the bogey (whose cross-section is smaller than that of rails) would melt, partially evaporate, and turn into plasma. This plasma cloud would become a piston of sorts for the projectile, which must be electrically isolated from the plasma. In this connection, in the literature ever more mention is made of plastic projectiles. To achieve high firing rate, the contact between the plasma cloud and the rails is an important factor.

There is also the problem of terminating the acceleration. For the projectile to separate from the plasma cloud the latter would have to disappear or lag behind. In the simple arrangement under discussion no deceleration is possible and for the cloud to disappear the circuit would have to be broken. But breaking a high-current electrical circuit is known to cause enormous overvoltages and breakdowns. As a result, the projectile may get an additional random impetus with a transverse component. This in turn might drastically impair the angular accuracy of rail guns.

Lastly, the plasma piston itself is subject to a host of plasma instabilities, which are next to impossible to foresee and to remove.

There also exists a contactless way of accelerating a projectile based on a form of linear induction motor. In this motor a closed conductive ring is pushed

Table 1.8 *Characteristics of kinetic-energy weapons*

Kinetic-energy weapons	Typical speeds, km s^{-1}	Effective acceleration, g	Typical size, m	Typical acceleration time, s	Accelerated mass
Artillery	2–3	10^3–10^4	Tens	0.1	kilograms
Interceptor rockets	5–10	10–100	Units	10–100	Up to tens kg
Electromagnetic systems:					
fast	8 (predicted up to 20)	10^4–10^5	Hundreds	10^{-2}	1–1000 g
slow	3-5	10^3	Thousands	1	Tens kg

into a region with a smaller magnetic field. The ring moves along the axis of a chain of external magnetic coils to which in succession, in phase with the motion of the ring, a voltage is applied. Such a system was put forward by O'Neill for the so-called 'mass-driver' [illegible], which could eject from the lunar surface large amounts of matter (up to hundreds of kilograms per shot) and with a high angular accuracy (about microradian) at that. A shortcoming of this system is the relatively low effective acceleration (100g), and hence impressive overall dimensions (tens of kilometers!).

But perhaps the most critical problem for electromagnetic systems is power requirements.* At present typical energy sources for electromagnetic systems are unipolar generators (flywheels) with energy capacities up to 10 J g^{-1} (10 MJ t^{-1}) [illegible]. In case high firing rate is required, the system must store the energy needed with the result that its mass might be up to a thousand tons (given the present state of the art, of course).

In conclusion, electromagnetic systems (using magnetic field pressure) have the following two main inherent drawbacks:

— large overall size, which makes retargeting difficult (with recoil taken into account), impairs the firing rate, and makes them more vulnerable, and
— unduly massive power supplies.

Therefore, electromagnetic systems, which have so far only been oriented at achieving 'supervelocities,' at the current stage of their development appear to be inadequate candidates for the main method of launching homing interceptors (we have not even discussed the enormous overloads inherent in such systems which may hinder the operation of sensors and other elements).

The prospect of using individual ballistic interceptors of such a type, even high-speed ones, seems to be remote, at any rate for large ranges, due to uncertainties of their angular accuracy.

The situation may be better for shorter range interceptors, if they are needed in space. Another possibility is to use 'space shrapnel'—a cloud of relatively small fragments fired in the direction of a target and covering a large

Power requirements	Intercept mode	Main limitat
Some cordite	Ballistic Homing (?)	Final speed limited by speed of cordite gases
Much fuel	Homing	Large initial mass and final speed
Large installation	Ballistic	Magnetic field is limited by mechanical and thermal strength, plasma instabilities
Same	Homing	

volume around the target (in that case the accuracy requirements are not critical). The various forms of kinetic-energy weapon are compared in Table 1.8.

1.4 Microwave electromagnetic-pulse weapons

It is common knowledge that nuclear blasts are accompanied by intense pulses of electromagnetic radiations, which disrupt and destroy electronics within thousands of kilometers. In our description of the mechanism of producing an electromagnetic pulse (EMP) we will follow the approach given in [illegible].

* For more details see Chapter 3. —*Eds*

In a nuclear explosion most of the fission products formed are in an excited state with excitation energies of about 1 MeV and an exceedingly short lifetimes as compared with the passage time of the detonation front, which is about 10 ns. Consequently, gamma-quanta are emitted almost instantaneously. These gamma-photons interact with air molecules to form Compton electrons moving chiefly in the radial direction. In order that the system might be an emitter it must be made asymmetric. A high-altitude explosion, for example, is asymmetric because the atmosphere thins out with altitude. The density of the Compton electrons being proportional to the air density, it is only natural that the electron cloud develops a finite dipole moment. The electrons spiral around the lines of force of the geomagnetic field and generate electromagnetic radiation. Another EMP mechanism is associated with the X-ray radiation of a nuclear explosion, which ionizes the atmosphere affecting in a pulsed manner the structure of the geomagnetic field. This interaction is transmitted over long distances.

Since on average each fission event yields 200–250 MeV, the instantaneous gamma-photons carry away 0.4 per cent of the explosion's overall energy. It is thought that about 0.6 per cent of the gamma-photon energy goes over into the Compton electrons to be then reemitted as an EMP.

In a megaton explosion the electromagnetic pulse has an energy of

$$4 \times 10^{15} \times 0.004 \times 0.006 \simeq 10^{11}\,\mathrm{J}. \tag{1.50}$$

Since the EMP is assumed to last for 10 ns, the energy density in a 3-m thick 1,000-km radius spherical wave caused by a nuclear blast will be

$$\varepsilon = 10^{11} \times 10^{7}/(4\pi \times 10^{16} \times 300) = 3 \times 10^{-2}\,\mathrm{erg\,cm^{-3}}. \tag{1.51}$$

For the electromagnetic wave $E^2/8\pi = H^2/8\pi = \varepsilon/2$, whence the electric field is

$$E = (4\pi \times 3 \times 10^{-2})^{1/2} = 0.6\,\mathrm{CGSE\,units} = 180\,\mathrm{V\,cm^{-1}}. \tag{1.52}$$

In such a field the potential drop across a space object 25 m long will be 450 kV. The resistance of the object at 1 MHz (the characteristic frequency emitted by 1-MeV electrons in the geomagnetic field 0.6 G) is estimated to be 10 ohms. In consequence, the current flowing over the satellite's surface will be 45 kA. This current can, through some capacitive and inductive couplings, penetrate inside the object to produce voltage transiency with an amplitude of about 1–100 V.

The corresponding flux of electromagnetic high-frequency energy is fairly small: at 1,000 km from the explosion site it is only 10^{-6} J cm^{-2}, the power being 100 W cm^{-2}.

EMP weapons thus deposit on a target's surface 100 W cm^{-2} or so of high-frequency electromagnetic energy.

We will concentrate on the microwave radiation. According to literature evidence, a number of US laboratories are developing generators for these radiations, the emphasis being on raising their powers. It has earlier been noted that diffraction constraints do not allow microwave energy depositions of around

kilojoules per square centimeter on targets, this being the value needed for the thermal destruction of a target. There are no such constraints for depositions several orders of magnitude smaller.

For example, an antenna 10 m in diameter produces a microwave beam with a divergence of about 10^{-4}. At a range of 1,000 km such a beam would form on the target a 100-m spot (of the order of a large battle station). Generators are now available (e.g., called gyrocons) with power varying from 0.1–1 GW, [illegible] These generators could provide energy depositions from 1–10 W cm^{-2}, a figure far below the required 100 W cm^{-2}, but not to the extent that would warrant technological pessimism.

In its typical operational regime a gyrocon sends out trains of microsecond pulses. The energy of each pulse is enough to provide a deposition of 10^{-6}–10^{-5} J cm^{-2}, even higher than earlier estimates. There is one other favorable circumstance: the frequencies used (hundreds of gigahertz) are much more penetrating than the lower frequencies (megahertz) typical of the EMP weapons. It may well be therefore that there are already microwave generators that can produce some equivalent of an electromagnetic pulse at ranges up to 1,000 km.

Powerful electromagnetic radiations can also be generated when high-current relativistic electron beams interact with the atmosphere. In the process, up to 10 per cent of the beam's energy is transformed into electromagnetic radiation, which propagates more or less isotropically. For 10-MeV 10-kA electron beam, say, the power of the radiation may be as high as tens of gigawatts but, because of the isotropic nature of propagation, the kill radius does not exceed a hundred meters.

Prime targets for EMP weapons would be the power supplies and control and guidance systems of missiles, as well as the antennas of satellites and space-based battle stations.

Since microwave pulses pass unhindered through the atmosphere, EPM system may be deployed both in space and on the ground. In terms of energy per shot (microseconds), the outputs, generally speaking, are not large—no more than a dozen kilojoules. Also the electrical efficiency of gyrocons is high—50–70 per cent. Therefore, the mass constraints for the power supplies of space-based EMP systems are not that severe.

A natural protection against EMP's is thoroughly to screen electrically all the vital elements of a missile.

1.5 Conclusion

It follows from the analysis given in this chapter that although some of the weapons considered could in the future be made to meet the requirements for a hypothetical space-based ballistic-missile-defense system, the overall problem of developing and deploying such a system is as yet far from being solved. One of

the cardinal delusions of SDI enthusiasts, according to some US researchers, is that individual breakthroughs in some areas (e.g.,destructive mechanisms) are claimed as heralding the advent of an entire effective defense system.

The versions of the directed-energy weapons designed to kill attacking missiles and warheads can be used for other purposes, e.g.,to destroy satellites (including space-based battle stations). In the latter case kill thresholds may turn out to be much lower than those needed for missiles and warheads, and the targeting and tracking are simpler, and the time constraints less severe. Consequently, the space-based components of a BMD can be destroyed using similar systems.

It has been stressed repeatedly by the experts that the major difficulties in fashioning a ballistic-missile defense will be concerned not with the development of the requisite weapons, i.e., destructive components as such, even though, as we have just seen, the problems are many. The major obstacles would be elsewhere.

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Chapter 2
Space-based battle stations

The task of destroying enemy's ICBM's throughout their trajectory, above all in boost phase, calls for mounting in space a constellation of near-earth components of the defensive system. These may be both weapons or their components (e.g., relay mirrors for ground-based lasers) and the various surveillance, acquisition, tracking, control, and power supply systems.

Despite the fact that these components of the proposed US nation-wide BMD are in different stages of research and development efforts, even now, to a high degree of confidence, one can bring out some of the fundamental problems that would plague the developers of the space-based components of the defense.

The components launched into near-earth orbits, whatever their purpose, must fulfil a number of principal requirements, namely, they must:

1. Stay in orbit 'on station' for long periods of time.
2. Be self-contained throughout their life or be supported by an effective supply system.
3. Be exceptionally reliable, fast, and have a sufficient resource of weapons.
4. Be immune to all sorts of impacts, accidental and deliberate.
5. Be able to operate quickly and function under pressure.
6. Maintain constant links with other BMD elements.

Detection, tracking and aiming means, although unequal to the formidable requirements of a BMD system, have for decades been deployed on satellites and have proved to be successful enough. The deployment in space of advanced systems of that kind suitable for a BMD will obviously not pose any new challenging problems. There will still remain many difficult problems although, such as vulnerability and reliability of the BMD satellites, the scale of these problems is hardly comparable with the problems to be faced in launching, deploying, and operating the weapons themselves. It is this aspect of the formidable task of fashioning the space-based component of the antimissile defense that will be mostly discussed in this chapter.

One important factor defining the operational readiness and efficiency of the space-based component is the *reliability of space battle stations.* Here we must distinguish between two reliabilities: *technical reliability* and *operational* (combat) *reliability*.

2.1 Technical reliability

This parameter determines the 'on station' capabilities of a satellite, and hence its useful in-orbit life.

The parameters of the hypothetical antimissile weapons that could be utilized within the framework of a BMD leave no doubt that space-based battle stations would have masses measured by hundreds tons. With this in mind one is led to conclude that the quick replacement in orbit of a station that has served its rated life is going to be quite a challenge. And it is highly unlikely that, at least in the foreseeable future, such station could be put in orbit using a single launcher. Consequently, the deployment scheme would obviously have to provide for putting in orbit blocks of a station to be assembled later in space. Assembly operations would necessitate special-purpose tools and equipments, most likely massive. Thus, the replacement of disabled or exhausted stations would require putting in orbit substantial additional hardware and it would be a prolonged operation, to the detriment of the effectiveness of the entire space-based component. This in turn would pose the question of the necessity of the regular replacement of exhausted hardware with all its implications (organization of regular visits to the station, availability and interchangeability of repair tools and parts). Today it is hard to encompass all the details of the task. What is clear is that solving this formidable problem, or rather set of formidable problems, would be unbelievably expensive in terms of resources, time, and money.

The requirement that a station be highly technically reliable means that all of its units must have the maximal possible technical reliability and the maximal life in orbit. According to SDI spokesmen, the estimated failure-safe life of a battle station is around ten years. They also note that during this time the station must be fully ready for action not only without overhauls but also without regular maintenance.

This is an exceedingly stringent requirement. Under terrestrial conditions, where repairs and regular maintenance can be implemented much easier on the whole, the above reliability requirements would make no sense economically. Up until present we have no experience whatsoever of dealing with technical systems that could boast such a high technical reliability, and so the task pursued by the SDI leadership appears to be technically infeasible. At present it would be difficult to say what problems might emerge in solving the task, but even now one can maintain that the task would call for the development of an extensive panoply of fundamentally new testing and quality control techniques, and still there would not be a one hundred per cent guarantee of reliability.

It is important to underscore that all the elements of the BMD system will, because of the stringent specifications, of necessity be created using state-of-the-art technologies. This too would not make for improved reliability both of individual units of the system and of all the space-based components of the antimissile defense system. Present-day international practice, specifically the many

decades of experience gleaned in military and civilian aerospace engineering, shows that complicating any device, even a thoroughly proved and common one, while improving its efficiency, generally curtails the life between failures of the device and calls for more maintenance.

In consequence, the planners and designers of the BMD system would apparently have to blaze their path between Scylla and Charybdis: for one thing, in order to achieve the acme of combat efficiency they would have to employ the most advanced technologies; for the other, they would have to ensure unthinkable levels of technical reliability not only of individual components but also of the entire system.

One of the few possible ways of solving the task is to use redundancy (at times multiple stand-bys) for units and whole battle stations. This in turn would overly increase the overall size and mass of a station, which in addition to the redundant equipment would have to include extra controls to carry out periodic checks of units and, in case of failure, cut them off and activate the appropriate stand-by element. Furthermore, a fleet of stand-by battle stations in space would seem to be required.

The technical reliability requirement for each battle station and each other BMD component deployed in near-earth space presents problems of major proportions not only of technical but also of military and political nature. For example, a failure of any of the important units of a space-based battle station in combination with an error or foul-up in some element of the battle management system might precipitate an unpredictable response from the entire exceedingly automated decision-making mechanism in charge of the space-based ballistic-missile-defense system. Put another way, there is a certain probability that combinations of technical failures may arise in various elements of the antimissile-defense system that may cause a spontaneous activation and even operation of the entire BMD system.* The implications of such a fateful event would be so horrible that, however small the probability, it cannot be ignored. What is especially important here is that there are no ways whatsoever in the offing to solve this vital problem. Redundancy not only fails to answer the issue, on the contrary, it may only aggravate it, since with more elements in the system the probability of failures in one or several of them, and hence the probability of fatal combinations, becomes higher.

Whilst on the subject of technical reliability of battle stations, a word about the requirement of ten years of their failure-free operation is in order. Even should that most high reliability level be achieved for each station and each component in the defense system, the mean time between failures of the entire BMD system will be lower by far. A defensive system will take several years to deploy in space. Thus, the interval that elapses between placing in orbit the last station and the moment when the first one needs repair or maintenance will at best be several years shorter. Later on, maintenance and repair will have to be carried out vir-

tually on a permanent basis, even if there is no serious trouble in the system. Hence, even with the highest reliability requirements for the space-based components, their deployment and sustaining in proper working order will themselves be colossal undertakings far beyond current capabilites.

2.2 Operational reliability

Another aspect of the reliability issue of space battle stations is their serviceability under war-time conditions, when accomplishing the jobs they were designed for, namely, the destruction of the enemy's ICBM's. The operational reliability of a combat system is essentially its ability to operate and achieve combat goals under any conceivable conditions. In addition to technical reliability under most unfavourable conditions, one should also take into account war-time performance capabilities subject to countermeasures. Clearly, any battle station would have predetermined firing capabilities, i.e.,it would be designed to perform its combat duties within a certain time. It is also clear that, just like any other technical system, the station would be most reliable under the optimal conditions, whereas prolonged operation under maximum loads and countermeasures might well lead to failures and errors in some of its components, and hence to a reduction in the efficiency of the BMD system as a whole.

To avoid such a hazard, reliability requirements to the station must be based on the values of its parameters more unfavorable than those that at the moment are regarded as optimal. This would make one look from another angle at the weight-carrying capabilities and the fleet size of the space-based strike weapons as quoted in the US literature. Furthermore, inadequate technical reliability necessitates redundancy for major units to provide operational reliability.

Any space-based ballistic-missile defense is vulnerable to a wide variety of countermeasures. It has been noted in various reports that the most natural and the simplest countermeasure to any system would be to build up the offensive strategic arsenals, and hence the number of objects to be intercepted and destroyed by a BMD | .|. With more ICBM's on the opposite side the BMD would come under pressure, which in turn might affect its reliability. Another countermeasure would be to subject the opponent to more stringent time constraints. This may be achieved, for instance, by converting to fast-boost missiles and depressed-trajectory ICBM's, or by multiplying the number of warheads and decoys. A combination of these countermeasures should enable the attacking side to overwhelm the defense.

On the face of it, the answer would be to deploy more battle stations in space, a measure that would seem to relieve the load on each station. In the US literature this problem is, for the most part, treated from economic point of view, in accordance with the so-called 'Nitze criterion,' by which the efficiency of a BMD is linked to the ratio of the cost of deployment of more ICBM's to the cost

of deployment of more satellites needed to counter it | |. This approach seems to overlook the need for more surveillance, acquisition, and tracking satellites, for more power supplies, for more communication links and information processing facilities, etc., etc.

It would also be very difficult to attain adequate combat reliability by improving the weapons on the space stations. This in principle might be achieved for the optimal combination of such firing capabilities as defensive resource and firing rate. It should be borne in mind however that whereas simply augmenting the defensive resources is a feasible, though difficult, task, it would be much more difficult to improve the number of shots per unit time beyond the system's design capabilities.

The firing capabilities of a space battle station would be governed by a host of parameters both of the weapons themselves and of all manner of auxiliaries. The first and serious stumbling block is effective cooling of the station. The need for heat removal stems from the fact that none of the directed-energy weapons currently under consideration, including rail guns, would be particularly efficient. In action the battle stations would release huge amounts of thermal energy, which might eventually put the station out of action. Since the number of targets to be intercepted might be increased beyond expectation (in the first place by using more inexpensive penetration aids), one can be only too sceptical about some pronouncements concerning the 'heat-absorptive capacity' concept of station operation. The idea is that the station after having fired a certain number of shots saturates its heat capacity and goes out of commission. This approach would suggest that the entire ballistic-missile defense would be designed to handle a preset number of targets, which would be an incentive for the other side to expand its offensive forces.

It appears that cooling systems would be an integral part of any space battle station employing the weapons discussed earlier in the book. At the same time, all the present heat-removal systems, massive and bulky structures, are far too inefficient for the task in question.

Heat removal would be easier with gas-dynamic infrared lasers. But employing these weapons on space battle stations, although alleviating the heat removal issue, would give rise to a host of other problems. A laser installation of that type is a sort of mighty jet engine and a source of violent vibrations within a wide frequency range. These lasers, if employed as weapons in space, will thus require devices to compensate for the jet motion, which might spin the station or even remove it from its assigned orbit, and to damp the vibrations because vibrations are incompatible with the exceptionally high accuracy requirements. Moreover, vibrations could interfere with the functioning of some of the units in the laser block itself, so that additional alignments of individual units would be required.

The above examples and considerations only bring out some of the engineering problems involved. But they go to prove that the technological snags

that will be encountered when improving the performance of BMD weapons would be legion and they would be interrelated in such a way that solving one problem would give birth to another one, which at times would be even more complex than the previous one. All this would limit the possibilities of improving an antimissile defense system, and hence possibilities of accumulating the required reserve of operational reliability of the system and its components. At the same time the quantitative approach (i.e.,the provision of stand-by reserves of space battle stations) would be blocked by the possibility that the attacker could expand its offensive forces offering more targets to the defender with a view to saturate the ballistic-missile defense.

This strongly suggests that the battle stations would funcion under overloads, thus bringing into question any prospect that they would operate at high levels of reliability. This means that not only the performance of each station might be severely impaired but also that some of them might be put out of action and thus endanger the fulfilment of duties by the ballistic-missile defense as a whole. The situation is aggravated by the fact that the proposed BDM system could not be tested under real conditions and so there would be great uncertainties in assessments of the reliability of the stations and their support systems to be deployed in space.

One other important condition of serviceability and effectiveness of the space-based components of a BMD is protection of them against direct attack and active countermeasures. Antimissile satellites would themselves be fairly helpless against attacks by various, often fairly primitive and cheap, antisatellite weapons. Above all, this is because the stations and other space-based defense components would have appreciable overall dimensions and would travel in constant well-known orbits.

As for the issue of vulnerability, one is safe in saying that whatever the form of protection of the stations, they would all be expensive and would require much more material to be lifted into orbit. There are few ways of protecting stations that can be foreseen at present and they fail to respond to all the countermeasures possible. They mostly rely on manoeuvring the stations to dodge an intercept, disguising them, deploying decoys, or fitting stations with various passive protections such as shields or coatings. Another group of protective measures are active in nature, they presuppose creating around the station a sort of 'sovereignty zone,' such that the station would destroy any object within an established range.

The last approach, believed by SDI enthusiasts to be one of the most efficient ones, is worth considering in more detail. There is hardly any ground for optimism here because whatever the size of the zone it would be too small to protect a station against antisatellite weapons, say, against space mines. At the same time these zones could not be extended indefinitely without disrupting normal peaceful activities in space. With so many battle stations in space, and hence as

many 'trespassers will be prosecuted' signs, space would become a dangerous place in which any intrusion into those restricted areas, even accidental ones arising from an error or some navigational failure would be lethal for craft belonging not only to other nations but also to the owner of the 'antimissile shield.'

What is more, there is a fairly high probability of getting within these zones of meteoroids and other celestial bodies, dead artificial satellites and man-made space debris, the quantity of which today is assessed to be tens of thousands of pieces, and which will increase in the years to come. And so the stations would respond to each such 'violation of sovereignty,' however innocent. But the activation of the self-defense would, in all probability, cause the self-activation of the station, because an 'attack' on a space station would most likely be treated by the defender's battle-management system as a prelude to a full-scale nuclear attack. The other side, in turn, having noticed the activation of the opponent's antimissile defense might perceive that the opponent is about to inflict a first devastating strike, and would be forced to alert its offensive forces. These avalanche-like goings-on might occur so quickly as to allow no time to settle the crisis. A holocaust may ensue if the chain of events just described coincides with some political crisis.

Consequently, apart from the purely engineering and financial requirements, the protection of the space-based components would also be another of the many destabilizing factors in the tight world of the SDI.

Although the activation of a BMD, i.e., placing it on alert, would clearly be a most important destabilizing factor, the many levels of readiness of a station would be conditioned by its colossal power requirements. Even under base-load conditions (surveillance), the power consumption of the station might, depending on the equipment type, be as high as hundreds of kilowatts, i.e., scores of times higher than the capacities of today's space-based power supplies. Alerting a station would call for more power and, according to some estimates, the demand might be as high as several megawatts. Consequently, maintaining the station in a sort of 'hibernating' state is for now and the foreseeable future a technological 'must' because the development of heavy-duty onboard power sources capable of meeting the station's needs when on alert for prolonged periods (perhaps for years) would be a formidable challenge. Moreover, even if appropriate energy sources were made and orbited, it would be highly undesirable, without good reason, to overstrain them so as not to deplete them.

Generally speaking, the issue of developing space-based power supplies for a large-scale ballistic-missile defense is worthy of special attention. Even now it is clear that fresh technological breakthroughs will be needed here. Traditional supplies, such as solar batteries, radioisotope reactors, and accumulators which are used at present as energy sources for satellites, could hardly meet the demands of space-based battle stations of the proposed BMD. Relatively inefficient, they are massive and heavy structures. Space power engineering for military purposes is

likely to rely upon nuclear reactors with various energy converters. It is quite obvious that only nuclear reactors possess satisfactory power-to-mass ratios and can in principle meet the specified objectives, indeed they are the principal candidates for the task. They are not however without problems and these are yet far from solution.

First, nuclear reactors require efficient converters of the thermal energy they produce into electricity. There are three types of converters (for the foreseeable future): thermoelectric, thermionic, and turbo-generator converters. Each of them has its complementary advantages and disadvantages. The first two are relatively light-weight but fairly short-lived and they produce d.c. electricity whereas most applications need a.c.Turbo-generators produce a.c. current, but are massive and have vibration problems.

Second, nuclear reactors would have to be equipped with heavy, large heat sinks, because the only acceptable version would be a closed-cycle reactor.

Third, nuclear reactors would need hefty radiation shields to protect the onboard electronics from the wide spectrum of radiation, notably gamma rays and neutrons. This protection is of necessity massive, an extra strain on the weight requirements to the system.

Lastly, nuclear power plants have limited lifetimes. They are plagued by high-temperature corrosion and fatigue processes, which are responsible for the heavy wear on exposed structures. This in turn would call for more repair and maintenance. To conclude, with nuclear power supplies it would be exceedingly hard to reach the technical reliability level needed for a BMD system [2.3].

This brief evaluation of nuclear reactors as power supplies warrants the prediction that space battle stations would be powered by separate orbital power platforms stationed some distance from the users. The power supply component, apart from power plants proper, would have to include electrical transmission units, which again means that space stations would need additional hardware, another source of vulnerability.

2.3 Conclusion

Examples of the weak points of the space-based components of a BMD system might be multiplied. But even the above-mentioned challenges and contradictions associated with power supplies and other aspects lead one to reexamine the problem of fashioning a space-based defense. The wide range of often-conflicting requirements and operating conditions suggest the notion that what would be needed is not a self-sustained space battle station able to take care of all the functions concerned with intercept and destruction of the opponent's ballistic missiles, but a system (a component in relation to the BMD as a whole) with its elements located on spacecraft separated from one another and connected by some communication links. The battle station complex would have to comprise individual platforms for the station proper, power unit, data processing, and so

on. This analysis puts in question the assessments to be found in the US literature concerning the masses and costs of the space-based elements of a ballistic-missile-defense system. These estimates have been made on the basis of the postulated fuel requirements for the laser systems and the masses of the interceptor rockets. If the above factors are brought into consideration, it may well turn out that these requirements do not predominate either the total mass or the energy analysis of the space-based ballistic-missile defense.

At the same time, the key problem, it seems, resides not in the fact that battle stations deployed in space would have low efficiency and that their costs would be vastly higher than the figures quoted now. It is more important by far that the system would introduce a further element of instability into the present strategic balance. Oddly enough, the additional destabilization might come from the elements and components that at first blush seem innocent and neutral.

References

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Chapter 3
Some technical issues of terminal defense

As noted above, the advocates of President Reagan's Strategic Defense Initiative initially stressed the importance of space-based defensive components for intercepting ICBM's in boost phase, and also in midcourse, the two phases making up over 95 per cent of a missile's flight time.

Recently many Western experts have returned to the potentialities of ground-based and air-launched components for intercepting warheads in the terminal phase of their trajectories. To a large measure this is associated with the growing understanding of the intrinsic vulnerability and unreliability (at staggering costs) of the space-based components of the proposed wide-scale BMD system, as evidenced for example by frequent failure and crashes of spacecraft.

Renewed emphasis on terminal intercept offers a number of technological advantages. Above all, the time elapsed from the launch of an attacking ICBM to its reentry into the dense atmosphere is about 30 minutes. During this period the nation under attack would be able to identify the attacking missile in a more accurate and reliable manner, to get a fix on it, to work out the trajectories and to initiate terminal-phase interception. In the terminal phase the 'threat cloud' enters the atmosphere (at 100 kilometers) and at an altitude of about 60 km the friction with the air retards the penetration aids, whereas in front of the heavier MIRV's forms an ionized shock layer. This layer and the ionization wake in the air with glowing particles of MIRV's thermal insulation make it easier to aim defensive weapons.

Terminal-phase defense, however, is frought with significant problems. One difficulty is that the terminal phase is very short (about 1 minute), warhead typically hitting the ground with a velocity of about 3 km s^{-1}, and so the defense faces with formidable time constraints.

Two BMD schemes are possible, their tasks differing widely:

— exoatmospheric interception to protect large areas with targets not hard enough to survive a close nuclear blast;

— endoatmospheric interception for point defense of a hard target.

The first scheme is more complex by far than the second one, its complexity growing sharply with the size of the area covered. Larger areas call for more

interceptors, and a more advanced target tracking system, a one with higher speed and resolution. Also, the number of targets to be handled is higher due to the difficulties of selecting warheads against the background of decoys. Accordingly, extra (as compared with the second scheme) time for interception costs dearly—higher interception altitudes and, as a consequence, more targets to be hit to achieve a reliable defense of an area or an installation. Preliminary information about attacking MIRV's comes from ground-based precision radars.

In exoatmospheric interception to achieve accurate aiming the target must be detected by optical and IR sensors already at large distances. Since in this section of the trajectory a warhead has a relatively low temperature, far-IR sensors are needed, which are best installed on high-altitude aircraft to minimize the influence of atmospheric water and carbon dioxide molecules.

Thus, exoatmospheric interception relies on a sophisticated target acquisition system working under severe constraints caused by short times available and/or a swarm of targets to handle.

In endoatmospheric terminal-phase interception the variety of defensive weapons is smaller. Since the defensive weapons are stationed on the ground, or in the lower atmosphere (with airborne BMD's), directed-energy weapons are regarded as an ineffective answer to the problem, because the radiation source and the target warhead to be killed are separated by a dense atmospheric layer, in addition to the warhead's hard skin-shield. Defense here may rely on high-acceleration rockets stationed near the installations they cover. The area must be saturated with such interceptors.

Nonnuclear rockets can make an intercept either by hitting the target mechanically or by producing a dense fragmentation field in its vicinity. This would require exceedingly accurate homing and adequate identifying warheads among the threat cloud at altitudes where the atmosphere only begins to have its influence. Otherwise, a constellation of targets will have to be dealt with, most of them being decoys.

Another terminal-phase BMD alternative is the 'rocket swarm,' i.e., a swarm of small unguided interceptors launched in the direction of an incoming warhead. The swarm can throng up a region several tens of meters across at a distance of one kilometer from the installation covered. If the trajectory of the incoming warhead is determined correctly and the direction and timing of the launch are worked out adequately, the kill probability of the warhead will be fairly high. But this technique is no good for exoatmospheric intercept, since far away from the covered area the trajectories of the attacking MIRV's may diverge markedly. Since an attacking warhead may be designed to explode on interception such a solution is only suitable for defending hard targets, such as missile silos, which can survive a close nuclear explosion.

There are two features of a point terminal-phase defense that make the task simpler than area defense. First, the destruction of a hard target requires

that an accurately aimed warhead be detonated on the ground or at a low altitude. This enables the defensive system to intercept at altitudes and ranges of only several kilometers, thus allowing more time to compute the trajectory of a warhead and to aim the interceptor in on the attacking weapon. This improves the probability of a successful intercept because the possible-trajectory cone of attacking warheads has its vertex at the point target, which makes interception easier.

Second, the protection of a ramified network of hard installations allows a less effective defense. Even if the intercept probability is under 50 per cent, most military assets, e.g., ICBM silos, may survive.

It has been found, however, that every BMD scheme based on kinetic-energy impacts or detonation in the vicinity of an attacking warhead may be thwarted if the attacking warhead is endowed with a manoeuvring ability in the terminal phase of its trajectory. The best answer, from the technical point of view, seems therefore to be a missile interceptor armed with a nuclear warhead. But a low-altitude intercepting blast will nearly always black out the defender's own guidance systems and disrupt control and communication systems.

A ground-based antiballistic missiles relying on intercepting nuclear warheads in the terminal phase of their trajectories cannot create a reliable nationwide BMD.

The current US development of a new generation of air-launched antisatellite (ASAT) weapons can be viewed as a terminal-phase interception system. In terms of functional requirements the ASAT system differs quite markedly from the BMD system. On the technical side, however, the tasks of destroying a near-earth satellite and that of destroying an ICBM's warhead in the terminal phase of the flight have much in common. So, precision long-range homing systems and weapons used in the ASAT system are quite suitable for missile interceptors in some BMD schemes.

ASAT interceptors launched from fighter-bombers as such are of little strategic value for killing MIRV's in their terminal phase. In addition to being fairly sluggish (a satellite in orbit can be destroyed under less stringent time constraints), this scheme is not cost-effective because it calls for all too many expensive aerial launchers (up to 10,000 antimissile-carrier aircraft).

At the same time, the homing device developed for the ASAT project can be fitted on special ground-based antimissiles, which makes it possible to use the device in a BMD system. The same is true of the other ASAT components.

It is thus clear that the antisatellite weapons program can have as its spin-offs some components of a BMD defense.

Western strategic planners sometimes maintain that it is possible step by step to transform point or area complexes (systems) into a nationwide BMD by simply incorporating new targets or areas protected by similar BMD defenses and some space-based components.

But there is compelling evidence that the buildup of space-based components does not ease the requirements on separate-target or area ICBM defense. This is because in a full-scale ICBM strike it is in principle impossible to predict which MIRV's will be intercepted earlier in their trajectories and, hence how many warheads will reach a target or an area covered by a ground-based or air-launched antimissile weapon system for them to be intercepted inside or outside the atmosphere.

This consideration, among other things, accounts for the qualitative distinction between the limited ballistic-missile-defense system of an area, allowed by the ABM Treaty of 1972 and the Protocol thereto of 1974, and the deployment of a large number of such systems.

Chapter 4
Potential uses of space-based weapons against air and ground targets

The dialectics of the development of weaponry testifies conclusively that any division of weapons into offensive and defensive ones is arbitrary. As a matter of fact, only absolutely passive defensive systems can be considered purely defensive. But if a defensive system contains active strike elements, then it can at all times be used more or less effectively as an attacking weapon.

Clearly, this applies in full measure to a comprehensive space-based BMD. The deployment of weapons over an opponent's territory and the ability to transmit enormous amounts of energy nearly instantaneously over unlimited distances create unique possibilities for attacking various targets.

The majority of the reports that in some form or other touch on this problem conclude quite unequivocally that, whatever the limitations, the components being developed within President Reagan's 'Star Wars' program could be utilized to attack targets not only in space but also in the atmosphere and on the ground.

In view of these assessments, it does not appear accidental at all that this issue has not been mentioned so far in any of the official US documents on the SDI program. This is because the possibilities of obtaining, as it were, offensive spin-offs are in sharp contrast with all the 'defensive logic' offered in favour of the SDI.

In actual fact, new possibilities of striking from space at ground-based targets can in no way lend credence to the 'stabilizing character of space-based defense.'

The development and deployment of such forms of dual-capable space-based systems could give an impetus to offensive weapons programs that at the moment are hard to imagine.

Of course, the proposed anti-ICBM components and weapons would have different capabilities against air and ground targets. The SDI program relies on the following weapons (see Chapter 1):

— laser weapons;
— particle-beam weapons;
— kinetic-energy weapons;
— electromagnetic pulse.

The above weapons can be used for attacking air or ground targets depending on whether or not they can penetrate the atmosphere.

It is normally assumed that the atmosphere is transparent to *laser* radiation in the optical range, but this is an idealization. The visible and near infrared spectral ranges are shown in Figure 4.1. The abrupt drop in the shorter-wavelength part of the spectrum is due to the Rayleigh scattering by electrons, the

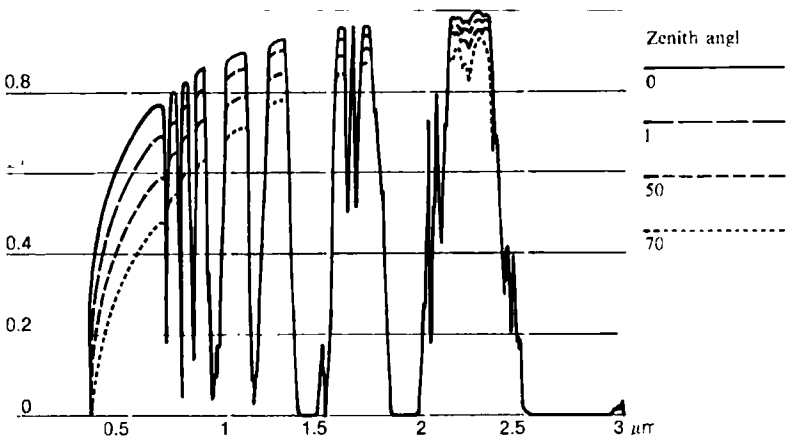


Fig.4.1 *Passage of a laser beam through the atmosphere from an altitude of 3 km corresponding to the residual mass of the atmosphere* (~750 g cm $^{-2}$).

scattering coefficient being inversely proportional to the fourth power of the wavelength. In addition to those in the picture there are narrow 'spectral windows' at 3.8 and 5 μm, and a fairly wide window at 8–13 μm (including the ozone absorption band at 9.7 μm).

If the laser wavelength happens to lie in an opaque region, it can in principle be shifted into a transparent region, although this may entail some energy losses.

The energy losses in the atmosphere are due not only to line absorption by atmospheric constituents and the Rayleigh scattering. Also important are macroscopic inhomogeneities caused by atmospheric turbulences or heating of the air by the laser beam itself. As a result, the beam may diverge a bit, thereby reducing the energy density, or fluence, of the beam—a most important parameter characterizing the lethality of a laser weapon.

It is hoped that the macroinhomogeneities could be neutralized for ground-to-space laser weapons using adaptive optics or the phase-conjugation technique. For space-to-ground laser weapons, however, the situation is yet unclear. Some experts believe that the problem can be solved with reasonable energy losses.

Other hindrances for beams of space-based lasers are clouds and smog, which might serve as effective shields against laser radiation. This imposes major constraints on the uses of space-based laser weapons against ground targets, although they could still be effective against aircraft at high altitudes, well above the clouds.

For the forms of *particle-beam* weapons (e.g., neutral H atoms) considered in Chapter 1, the atmosphere is an impenetrable shield. The atmosphere, whose effective thickness is 1,000 g cm^{-2}, imposes constraints on the energy of the particles used—it would have to be in the region of gigaelectronvolts. It is of course possible to station adequate accelerators in space, but they would still be ineffective weapons against ground targets. Immediately upon entry into the atmosphere hydrogen atoms would turn into protons, which would be deflected by the terrestrial magnetic field and scattered as a result of having passed through such an enormous thickness of matter. As a result, the current density (the lethality parameter of particle-beam weapons) would drop several orders of magnitude.

Another option that has attracted a great deal of attention lately is the high-current relativistic-electron beam, which claims to have better atmosphere penetration capabilities. In fact, under certain conditions the so-called 'gas focusing' is possible, whereby a beam travels along a pre-formed ionized channel through large distances without noticeable divergence. But this scheme is more suitable for ground-to-air weapons, since such weapons require powerful (and hence heavy) energy sources. And even if the source could be placed in orbit, the electron beam would have to cover large distances before reaching the dense atmosphere where the gas focusing mechanism would switch on. Meanwhile, the beam would have diverged, because of the space charge to such an extent that any effective gas focusing would be impossible.

Thus, it seems unlikely at the moment that the particle beam would be used as a weapon, if only an inefficient one, against airborne and ground-based targets.

The various types of *kinetic-energy* weapons (from high-speed fragments to small homing rockets) are able to penetrate the atmosphere, although one should take into account the following.

Current warheads reenter at 6–7 km s^{-1}, and their ballistic dispersion near a target is several hundred meters. Better accuracies (by an order of magnitude) are possible with radar guidance systems. Perhaps infrared homing could still improve the accuracy in attacking airborne targets, specifically aircraft.

Kinetic-energy projectiles attacking ground and air targets from space enter the atmosphere at much higher velocities. Even rough estimates show that the drag would vary as the square of the entry velocity, and even stronger for higher initial velocities. Therefore, the drag would be exceedingly high, and so would the frictional heating, neutralizing small fragments as kinetic weapons—they would just burn up in the atmosphere. This would also affect the

ballistic dispersion. On top of that, abundant heat release would, evidently, cause redouts of infrared sensors of homing systems.

One is thus led to conclude that today's kinetic-energy weapons are still unable to ensure the required accuracy when used against air and ground targets from space. Note that the accuracy required to achieve a direct hit is about that of the target's fix, and the latter cannot be lower than the target's size. Homing rockets may have heads that can increase markedly their effective surfaces (e.g., by opening an 'umbrella' several meters across) immediately before hitting the target. This could, to a certain degree, alleviate the problem of guidance.

Lastly, a word about the potentialities of the *EMP weapon*. As noted in Chapter 1, it can disrupt and even put out of action electronic circuitry. This type of weapon, generally realized as a microwave beam, would be especially effective in first strikes for causing blackouts of command posts and communications of the other side. Narrow microwave beams could strike from space some facilities on the ground and in the air. When a high-power microwave beam travels through the air, a high-frequency discharge may form, thus limiting the EMP capabilities. True, this is only characteristic for ground-based sources. Experience has shown that an electromagnetic pulse is especially effective against ground and air targets when it is produced by high-altitude nuclear blasts.

The EMP weapons differ from the laser weapons in two major ways:

— their efficiency is independent of weather conditions;

— the 'spot' made by a microwave beam on a target is typically hundreds of meters in diameter (see Chapter 1), so that accuracy requirements are lenient (recall that a laser spot is about one meter across).

It is worth noting, however, that the EMP weapons would be no good against hard targets, which are designed for maximum hardening to the nuclear explosions, including the EMP. This could severely limit the scope of targets susceptible to the electromagnetic pulse.

There remains the issue of the accuracy of fixing ground and air targets. Understandably, ground-based objects would present no difficulties, because they are connected to some distinct landmarks. Therefore, in what follows we will focus on airborne objects, namely airplanes and helicopters.

The Teal Ruby program now under way in the US has it as its goal locating aircraft from space using infrared detectors fitted in the focal plane of a telescope. The detectors are discrete arrays of charge-coupled devices (CCD), each CCD element (called pixel) being several micrometers in size.

The system senses the thermal radiation emitted by the aircraft's exhaust plumes. The temperature of jet exhaust is 600–1,000 K, which corresponds to a radiation maximum at a wavelength of 3–5 μm. To be more specific, we will suppose that we are observing through the 5-μm window. Suppose now that the objective lens of an IR-telescope is two meters across, then the diffraction limit is 3 microradian. From an altitude of 500 km this corresponds to a linear accuracy of about 1.5 m on the ground (about the size of a jet's plume).

If the focal distance of the telescope is, say, 5 m, then the diffraction-limited spot in the focal plane will be about 15 μm, the size of one pixel. Each jet engine will thus cover 1–2 pixels, and a good image of a four-gas-turbine airplane will occupy 10–15 pixels, which is quite enough for the target to be identified with high confidence.

Airplanes can thus be detected from space with a linear accuracy of several meters, which is a number of times smaller than the actual size of the plane. Reliable detection of a low-flying helicopter seems doubtful to date.

To summarize, among all the 'Star Wars' space-based arsenals, only the laser and EMP weapons are suited (with the above reservations) for destroying ground and air targets.

As stated in Chapter 1, the kill mechanism of the laser weapons is the destruction of thin-walled shells by thermal or impulse action. Apart from ICBM's, the laser weapons could be employed against other thin-walled targets, such as aircraft and fuel storages. Lastly, a powerful laser beam can simply ignite forests, wooden structures, plastic shelters, and so on, and this would not require the high firing rate of a ballistic-missile defense. Also the power requirements of the radiation sources would then be less rigorous, and so, technologically, lasers might be used more easily as offensive weapons than as planned in the SDI.

Earlier in this chapter we mentioned that using lasers against ground targets could be hampered by the weather. But aircraft are more vulnerable, especially when at high altitudes. It should be emphasized that ballistic missiles and airplanes are virtually equally vulnerable to the laser weapons, but airplanes are much slower targets, which simplifies aiming at and holding the beam on the target.

The prime targets for air attack by space-based laser weapons would be strategic bombers on patrol or those alarmed by a nuclear attack warning. The key problem here is reliable recognition and tracking of targets.

If the problem of reliable detection and effective destruction of the enemy's aircraft systems over the enemy's own territory is solved, this would change the strategic landscape beyond recognition. Laser weapons could then be used not only against strategic bombers, but also against the airborne command centers designed to perform the important troop control functions. Until fairly recently it was widely believed that the main advantages of such centers are the difficulty of detecting them, their mobility, and their invulnerability. These airborne centers are important compliments to ground-based command-and-control facilities, which are now becoming ever more vulnerable to a nuclear attack. Should these air systems become vulnerable, the entire battle-management system would have to be radically restructured. Consequently, if one takes into consideration the awesome potentialities of the above-mentioned weapons for destroying early warning and communications satellites, it becomes clear that the side that would create and deploy a space-based ballistic-missile-defense system

would at the same time be capable of effectively inflicting a preemptive strike with a view to black out simultaneously all the components of the command-and-control system of the other side. It is worth stressing that a major advantage of a space-based BMD would be its ability to kill airborne aircraft systems over the adversary's own territory, which cannot be done satisfactorily with today's weapons. This circumstance, it seems, may be another of the important incentives for the development of this class of systems, providing, of course, that the problems of acquisition and aiming are solved successfully.

From the above considerations we can distinguish several altitude zones with varying degrees of vulnerability to space-based laser weapons.

20–30 km altitudes. The atmosphere here is fairly rarefied; the effective thickness at 20 km is 50 g cm^{-2}, and at 30 km only 12 g cm^{-2} (at sea level 1,000 g cm^{-2}). Mother-of-pearl clouds occur at 20–30 km; and noctilucent clouds at 80 km, but these occurrences are extremely rare. All aerosol and turbulent layers lie much lower.

10–20 km altitudes. The aerosol layers appear at about 20 km, and the highly turbulent regions (the so-called 'jet streams') occur at 10–15 km. Cirrus and cumulus clouds reach 15–16 km, although their coverage there is small. And so at 10–20 km natural factors begin to affect the efficiency of laser systems as weapons.

Lower altitudes. Here clouds are the predominant factor: nearly half the earth's surface is overcast. Man-made aerosols, strong local scatterers of laser beams, are denser here. Clouds and aerosols reduce by more than half the lethality of laser weapons at these altitudes (averaged over large areas including different climatic zones). Thus, for airborne targets to be destroyed reliably at low altitudes, the power of the radiation sources would have to be increased significantly, but even this, under certain conditions, may not be sufficient.

As regards the possibilities of destroying ground-based targets by lasers from space, there are even more uncertainties. Space-based laser weapons, although sufficiently powerful to destroy ICBM's in flight, would obviously be impotent against a wide variety of hard ground targets, such as missile silos, strategic command centers, aircraft under hard covers, and so forth. As shown above, space-based laser weapons would be extremely sensitive to the weather conditions over prospective targets. This makes it possible, in principle, to protect important installations by using all kinds of smoke screens or other artificial scatterers of laser radiation.

It is substantially simpler to attack softer targets, since they are more vulnerable and numerous, and countermeasures are more difficult to engineer. Unhardened ground structures are estimated to be capable of withstanding an energy deposition of 0.1–1 kJ cm^{-2} (for igniting combustible materials) and 1–10 kJ cm^{-2} (for melting metal shells unprotected by absorbing or reflective coatings). Comparing these estimates with those for the walls of the fuel compart-

ments of ballistic missiles (10–20 kJ cm^{-2}) leads one to conclude that space lasers, which would be able to kill ICBM's in their boost phase, could also be used to strike a wide range of unhardened ground targets.

But for any final conclusion to be reached one should also take into account the attenuation of laser beams in the atmosphere, especially in the lower atmosphere, which are highly contaminated by all kinds of pollutants. The absorption and scattering losses range from 10 to 80 per cent, depending on the laser's wavelength and the specific atmospheric conditions. For continuous-wave lasers, these losses might to a large extent be made up for by longer dwell times as compared with those allowed for destroying an ICBM in boost phase. But this approach is not without flaws, since it makes heavier demands on the power supplies of space-based laser weapons, which are already too high as they are. What is more, it remains unclear how the transmission coefficient would change when the air temperature along the laser beam rises due to larger dwell times.

These considerations all strongly suggest that even under favorable weather conditions, laser systems of a space-based BMD seem to have limited applicability against ground hard targets. Laser weapons, however, could be used to attack all sorts of civilian targets, and components of the military infrastructure, such as oil storages, refineries, and depots. They would also have a certain potential for damaging such targets as transport ships, troop and material concentrations, and so on. One of the most important characteristics of space laser weapons in this case would be that the above-mentioned targets could be attacked wherever they might be stationed: in the front-line area or deep in the adversary's territory. All of the above advantages and capabilities of space-based lasers used as weapons against ground targets might come to nought if the weather conditions are unfavorable.

The variety of capabilities offered by battle stations in space, which could bring weapons close to any point in the adversary's territory, gives rise to a further danger. Having deployed in space a fleet of such stations, one side might be tempted to install nuclear missiles on them to attack the other side's ground targets.

The deployment of a space-based BMD would lead to a fundamentally new strategic balance. A unified system of command, control and communications to coordinate the performance of all space platforms would make this scheme more attractive to a potential aggressor.

Some US military and strategic scenarios consider the hypothetical case in which space-based BMD's are at the disposal of both sides. Basing nuclear weapons on a space battle station would make them invulneralbe to several (and the most efficient at that) BMD components when they are used against ground targets.

To be sure, this would be a violation of the 1967 Outer Space Treaty banning nuclear weapons in space, but the first move in this direction has already been

planned in connection with the development of the X-ray laser for a space-based ballistic-missile defense. As mentioned already in Chapter 1, this laser derives its energy from a nuclear explosion, thus suggesting that a nuclear device is planned to be placed in orbit. And although it is not supposed to be used directly for striking ground targets, this does not change the gist of the matter.

Space-platform-based nuclear missiles are small and light-weight, they can be put into orbit relatively cheaply and in quantity. One way of deploying them could be by replacing some of the space-based anti-ICBM missiles by nuclear-armed rockets. This replacement would hardly be susceptible to control by national technical means. If then it were decided to intercept ICBM's using nuclear arms (a scheme receiving much attention now), then all discussions of verification would make no sense, because any agreement banning or limiting the deployment of systems of this type would, by all intents and purposes, be impossible.

A nuclear attack from space would enable the attacker to strike any point on the globe within a relatively short time. Actually, if a space battle station orbits at an altitude of 500 km, then, the vertical component of a rocket's velocity being 8–9 km s^{-1}, it would take a minute or so for the rocket to reach its ground target.

The scheme just described could, as noted above, automatically render useless the two components of a comprehensive BMD of the other side, namely the boost and midcourse intercept. Viewed in this perspective, the scheme could be regarded as an effective countermeasure to a space-based ballistic-missile defense.

A disadvantage of this scheme is the much poorer accuracy with which warheads could be delivered as compared with that of current ICBM's. The velocity of entry into the atmosphere of a space-launched missile (the vector sum of the orbital and vertical components) would be 11–12 km s^{-1}. As noted above, this would enhance ballistic dispersion to the extent that radar guidance systems would be unable to correct it, since a warhead's trajectory would be too steep. From a technical point of view, the flaw does not seem to be insurmountable.

But the high final velocity could also become an important advantage, because it imposes formidable time constraints on the opponent's terminal-phase interceptor force. In addition, the much shorter total terminal-phase times, even shorter than those of today's medium-range ballistic missiles (MRBM's), e.g., of the Pershing 2 type, would be bound to affect the capabilities of the early warning system, and hence the entire BMD scheme.

Returning to the 'both sides have space-based BMD's' scenario, one should admit that the difficulties of verifying the absence of nuclear weapon onboard the other side's space battle stations would be a very strong incentive for both sides to deploy them. This would be another aspect of the strategical instability that might be caused by the proposed SDI program.

To sum up: a direct result of the deployment of a comprehensive space-based ballistic-missile-defense system would be to give unprecendented possibilities to the possessor of the BMD system to strike against the opponent's airborne command, control and communications systems, and perhaps against some ground-level structures. The proposed system, which is allegedly directed against ICBM's, would trigger a new round of the arms race in space, with space becoming a potential field of confrontation where the bulk of both sides' offensive nuclear forces would be stationed.

Chapter 5
Support components

5.1 Detection, identification, and targeting

A new generation of weapons for a space-based BMD would require radically new systems of detection and aiming, systems capable of providing the high accuracy, reliability and efficiency needed for the new weapons.

Detection and aiming capabilities are for the most part determined by the electro-optics of image forming.

US papers about the SDI plans have covered in detail the feasibility of laser, particle-beam, electromagnetic railgun and kinetic-energy weapons, the issues of beam convergence and focusing, and some questions concerning the orbiting of the weapons. But global surveillance and identification, acquisition, targeting, tracking, and hand-over from one defense layer to the next have all only got a superficial treatment, although each of these missions is exceedingly important and presents a swarm of technological problems, most of which are still waiting to be solved. All of the problems of developing precision systems of detection, identification, and aiming boil down to designing image detectors and interfacing them to on-board computers [5.1–5.3].

Let us take a look at the main demands on the sensors and some of the parameters that would enable them to carry out their missions.

Above all, these requirements are concerned with the very high probability of detecting, identifying, and getting an accurate fix on a target at large ranges, and also with timing the commands of pointing, acquisition, priorities (in case of several targets), and fire.

A major element of a precision, sensitive system of detection, identification, and aiming is the image detector (sensor) [illegible]. The most promising types of image detectors, according to US sources, are solid-state array ones, called charge-coupled devices (CCD's) or charge-injection devices (CID's) [illegible]. These sensors, being essentially a form of TV camera, are distinguished for their high reliability.

The sensor performs a wide variety of functions, the primary one being the digitizing the input information for a computer [illegible]. A CCD's photosensitive crystalline array transforms a light pattern into an electric signal, and makes it

possible to carry out some image processing operations before the target-identification stage [illegible], which is ordinarily done by the computer itself. The pre-processor stage includes:

— noise filtering;
— image enhancement;
— identification of a target's signature;
— pre-classification (input scene analysis for information content).

The processor would take final decisions concerning the target, its identity, and engagement priority (for several targets).

These devices have been in design and development stages in the US since the 1970s, within the *Smart Sensors* program. The sensors use very large scale integrated (VLSI) circuits and very high speed integrated (VHSI) circuits, which can solve a wide spectrum of technical issues concerned with filtration, detection, and preselection of videoinformation [5.3].

To be equal to these functions CCD arrays must form high-quality image signals. To this end, the size of a picture element, or pixel, of the input scene, i.e., the size of each CCD in the array, must correspond to the resolution patch (the smallest object on the ground that the system can distinguish) of the optical system at whose focal plane the array is positioned [5.3, 5.8, 5.9].

Resolution requirements. Let us assess the detection range and identification capabilities of the electro-optical system. We will assume that for a target to be detected by the system its image in the focal plane is at least as big as one or two pixels; recognition requires at least an eight-pixel image. These assumptions correspond to the well-known Johnson and Overington criteria for detecting and recognizing images with discrete structures [5.10].

The range of the electro-optical system is [5.11, 5.12]

$$R = \frac{x_n f N}{x_t n}, \tag{5.1}$$

where x_n is the size of the detector array, f is the focal distance of the optical system, x_t is the target size viewed by the system, N is the total number of pixels in the detector array, and n is number of pixels occupied by the target's image.

Considering the above, we obtain for $n = 1$ or 2 from (5.1) the detection range; and for $n = 8$ or 9, we obtain the recognition range.

According to (5.1) we can plot the detection and recognition ranges against the angular resolution of a diffraction-limited optical system (Figure 5.1), matched with the pixel size of the input picture. The size of the circle of diffusion produced by a diffraction-limited system at long distances is similar to that of the target's image in the focal plane of the detection system at long distances.

It was shown that the angular resolution of a target-detection system at a range of 5.000 kilometers is about 10^{-6}–10^{-7} rad for today's optical systems with a pixel size of several micrometers [illegible]. For example, the large IR-telescope

under development in the USA, with a 5-m mirror and 4-μm wavelength, provides linear resolution in the plane of the sensor, which by geometrical criteria [5, 12] is sufficient to detect and recognize a target at the above-mentioned ranges. According to other US studies of the high-quantum-yield low-noise CCD sensor [9, 10]

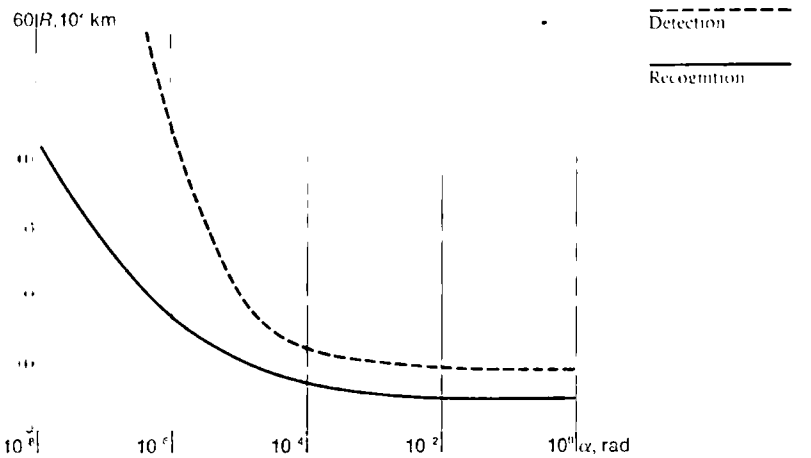


Fig.5.1 *Detection and recognition ranges against the angular resolution of a diffraction-limited optical system.*

used for precision passive surveillance on satellites, the sensitivity of the sensor's pixel drops sharply as its linear size decreases (Figure 5.2). Therefore, to have a

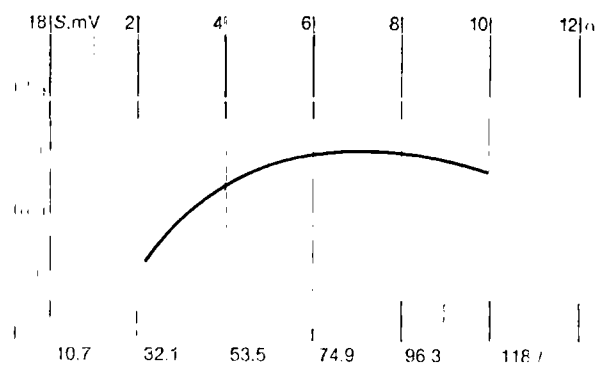


Fig.5.2 *Dependence of the sensitivity of the sensor's pixel on its linear size. Quantum yield of the layer 40%, signal-to-noise ratio is 6*

signal level sufficient for detection, one has to increase the pixel size. But this shortens the detection and recognition ranges by a factor of three and four, respectively, to give 1,650 km for detection and 1,250 km for recognition. If we make allowances for the velocity at which the sensor approaches the target and

also for the real time needed to process the image in accordance with the present US algorithms for detection and recognition, which are oriented to the television standard (t_{proc} = 25–30 ms), we will see that the task of developing a precision system of detection, identification, and aiming for the ranges in question is still far from completion.

With the real image processing speeds and approach velocities, the kill radius would de R_{kill} = 1,000 km which would be insufficient to engage all the targets in the boost phase.

In assessing such a system we should bear in mind that appropriate BMD components must in real time detect, identify and point not just single moving targets but many of them, sometimes thousands of them depending on the trajectory phase of the attacking ICBM's.

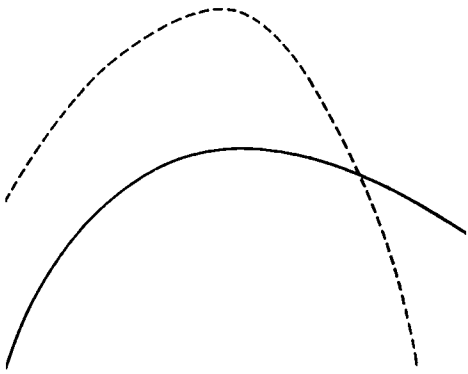
The *Smart Sensors* program is planned to be able to engage in real or near-real time up to 10 targets. There is some evidence that the task can be solved for two or three targets, and it is assumed that special arrangements of CCD and CID image planes will make it possible to handle 10 targets by 1990 [illegible]. With more targets, radically new approaches will be needed, obviously, to the management of multilayer hierarchical structures for image processing on the basis of such sensors supported by VHSI circuits, specialized computers and algorithms in order to obtain real or near-real time capabilities [illegible]. This is thus a problem in its own right, one that calls for special effort and analysis. At present the problem is far from solution and the prospect of it, in the opinion of many experts, is remote.

It thus appears that passive infrared sensors fail to comply in full measure with the specifications for the ranges of detection and recognition. The situation cannot be improved by enhancing the resolution (decreasing the pixel size) since this reduces the sensitivity of the array. The sensor could then function in the signal accumulation mode to form a charge pattern, but then the speed of the system is sacrificed.

Larger ranges of passive sensors would be possible if pixel sizes could be reduced and at the same time shorter wavelengths were employed (e.g., visible or ultraviolet). But it should be taken into consideration that the electrical signal of solid-state arrays is determined by the quantum yield of the photosensitive layer of the sensor, i.e., by the charge pattern formed by the light pattern on the surface of the array. It is to be noted that the quantum yields of current photosensitive coatings (silicon compounds) are so distributed over the electromagnetic radiation spectrum that their maxima lie in the 'red' and 'infrared' parts of the spectrum (Figure 5.3), the curves falling off in the 'violet' and 'ultraviolet' ranges. Therefore, seeking longer ranges of the sensors one should remember that the advantages gained by a better resolution due to shorter wavelengths can be offset by poorer quantum yields in that spectral range. Matching the parameters of a receiver to 'short' wavelength range, as follows from a number of US publica-

tions, is an independent technological problem whose solution awaits new photosensitive materials.

The range can be increased using active systems. According to some US developers, a prime candidate is the 10.6-μm laser radar. The longer ranges of the active systems—their main advantage—are mostly due to higher signals at the



output of a pixel, even though the quantum yield remains unchanged. It should, however, be remembered that the issues of resolution and the related problems of beam divergence and accuracy of acquisition and tracking are virtually the same as with the laser weapons. These problems could be solved by placing into orbit a laser emitter with an adequate scanning system (which would provide detection) and an adequate acquisition and tracking system. The total mass of these systems would be higher than that of a passive system. By way of example, the present US laser radars designed to cover wide ranges may weigh several hundred kilograms with their gyrostabilized servo drives. But passive systems based on microcircuits need neither emitter nor precision optical focusing systems, and so they usually weigh several kilograms.

Furthermore, one should not overlook the well-known fact that a passive system is on the whole much more resistant to noise than its active counterpart. Jamming emitters at the wavelength of the laser radar in a BMD, as well as confusion reflectors, may foul up the system's operation.

Speed requirements. These pose many problems associated with the architecture of the photosensitive array, the architecture of the processor memory, and also with the development of fast algorithms for identifying several hundred targets in real time. All of these limitations boil down to the overall problem of

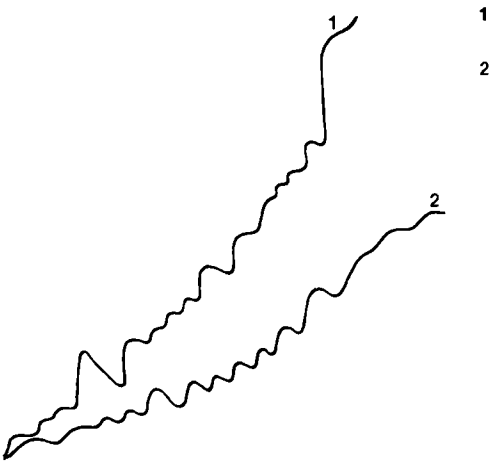
developing a specialized computer using VHSI circuits and a sensor to input information into the computer .

The high-accuracy specifications for the acquisition systems, which are linked with resolution specifications, require the use of smaller pixels with the result that many pixels get involved in the transformations demanded by the established algorithms. All this, in turn, slows down the computer. The number of targets (tens, hundreds or even thousands) to be identified and allocated for engagement predetermines the computer memory capacity and computer time.

The devices with artificial-intelligence being developed within the *Smart Sensors* effort are reported to be able to identify from one to three targets and set their engagement priorities with speeds that, as a rule, correspond to the TV standard, i.e.,a picture covering all of the photosensitive array takes about 25–30 ms to process. To be sure, processing more targets takes more time, and in a number of cases the dependence is nonlinear. Further, unclassified descriptions of the *Smart Sensors* developments contain no evidence for specialized sensors capable of handling more than five targets in near-real time.

A space-based sensor-computer complex would require powerful computer capabilities, i.e.,several billions of operations per second.

The sensor-processors have evolved from relatively simple devices that perform comparisons of an incoming image with a reference stored in the memory, through processors that perform 'sampling studies' of the input scene to processors that offer much wider possibilities.



Using these technologies within the proposed space-based BMD scheme would be rife with problems. Exceedingly large ranges, and hence very weak signals from targets, impose formidable demands on the sensitivity of the sen-

sors. In a number of cases, the target signal must, to improve the trustworthiness of detection, be integrated over time for a distinct charge pattern to form on the array [illegible]. This trick, however, not only reduces the speed of the system but leads to another complication. Under certain conditions as the useful signal builds up, so does the noise (Figure 5.4), and hence grows the probability of false alarm ($P_{f.a.}$). The developer of a sensor processor is thus confronted with conflicting requirements: choose an accumulation time such that, one, the resultant charge relief be good enough for processing, and two, the $P_{f.a.}$ be below a preset value. When compromising the developer must take into account the variation of the probability of correct detection with the signal accumulation time. These functions are given in Figure 5.5 for different signal-to-noise ratios, which depend on the properties of the photosensitive layer.

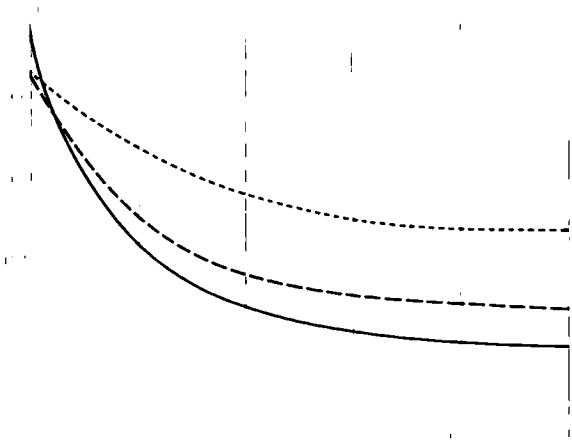


Fig.5.5 *Probability of correct* [illegible]

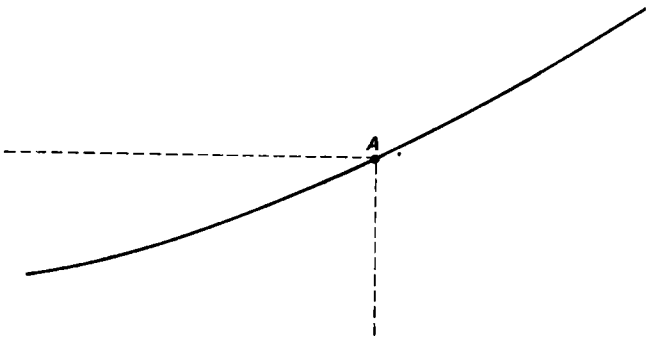
According to US criteria, the efficiency of a sensor-computer complex is judged from the acquisition probability given by [5.10,5.14]

$$P_{acq}(w) = P_d + (1 - P_d)P_d + (1 - P_d)^2 P_d + \ldots + (1 - P_d)^{w-1} P_d, \qquad (5.2)$$

where P_d is the detection probability, and w is the shortest integration interval for which $P_{acq}(w) > \rho$, where ρ is a predetermined value.

It follows from expression (5.2) that the acquisition probability P_{acq} is dependent on P_d and $t_i = w$. Examination of the plots in Figure 5.5 and equation (5.2) shows that the detection probability P_d tends to a constant, and so for rather long w (say, 50 ms) the acquisition probability may be virtually unity. This is, however, true of photosensitive layers with low intrinsic noise. It should be noted that the detection probability at low signal levels (at extreme ranges) is mostly determined by the detector's intrinsic noise. Shown in Figure 5.6 is the probabili-

ty of the detection of a target as a function of intrinsic noise of the commonest photosensitive layers. For today's photosensitive layers the intrinsic noise corresponds to point A in Figure 5.6 where the probability of detecting one target is



0.4. But the acquisition probability for these parameters and integration time 50 ms is 0.5. This is a very poor performance, especially from the viewpoint of the efficiency requirements for an antimissile system. Higher acquisition probabilities must await low-noise materials for the sensitive layers of the CCD-array sensors

5.2 Battle-management system

A battle-management system (BMS) for a comprehensive space-based ballistic-missile defense would be a computerized complex called upon to solve, as a minimum, the following tasks:

1. Collection, preprocessing, and up-dating of the information about launches of hostile ballistic missiles.
2. Calculation of the trajectories of the missiles and their MIRV's.
3. Engagement of the targets according to the 'rules of engagement' for the laser, particle-beam, and electromagnetic railgun weapons, and interceptor aircraft armed with antimissiles; targeting nonnuclear homing missiles, timing the destruction of the targets in each defensive layer, correlating the data on the 'leakage' of the targets through a given layer and handing them over to the next defensive layer.

The most significant problems developers are likely to face with any form of BMS are architecture, vulnerability, degree of delegation of responsibility, testing and software debugging.

5.2.1 Architecture

A trade-off of BMS architecture concepts must be based on the tasks to be fulfilled by the system (listed above), and on an analysis of its other performance specifications involved in solving these tasks.

In our opinion the most important requirements are the following:

Collation of data from the sensors with data on the general strategic situation, a mission that is only possible if the BMS has a model of the current strategic situation which is continually updated with the information not only from the battle stations but also from other sources, which may be beyond the information-gathering capabilities of the stations' sensors. Only by correlating inputs concerning the other side's launches with the general strategic landscape would the BMS be able to distinguish between threatening activities from other kinds of activities, e.g. launches of satellites and meteorological rockets, and so on.

At the same time, the need for a strategic model in a battle-management system turns the latter into a complicated configuration with some elements of artificial intelligence. Developers in the USA are well aware of this need and at present the issue is the subject of heated debate. A BMS based on this concept would become a huge *expert system* with rules of inference and principles of evaluation of a strategic situation as yet unclear and unestablished.

The most important 'architectural' conclusion is thus that a BMS would have to *store* somewhere *the strategic model*, or have a 'central processor' of sorts. Different approaches here give rise to a variety of architectures to be discussed later in the section.

Political and military leaders would have to exercise *permanent control* over the ballistic-missile defense. This would impose certain constraints on the system's architecture, which would have to provide for reliable communications with the battle stations to keep them under control.

Formidable computational capabilities would be needed for the battle-management system to ensure the efficient engagement of all hostile missiles by the battle stations. The software would process the information received from the local sensors and would have not only to compute the trajectories of each attacking missile but also to distinguish warheads from decoys, to identify the exhaust flames of the ballistic missiles being launched, to single them out from other heat sources, and so forth.

These features impose a number of conflicting demands on the BMS architecture. There is a wide spectrum of possible architectures at the extreme ends of which are:

a. Complete centralization, with all the operations controlled by the central processor, and
b. Complete decentralization, with each battle station being entirely self-sustained.

In our opinion, neither extreme solves the task as formulated above. This presents quite serious problems that, judging from the unclassified literature, have been poorly perceived at the design stage of this aspect of the ballistic-missile defense.

We now turn to the advantages and disadvantages of these two forms of BMS architecture.

Central processor architecture. Main advantages: ease of communicating between the system and the political and military leadership, ease of control for the entire BMS, cheaper electronics as compared with the 'decentralized' form, and simpler software (operating system). Main disadvantage: higher vulnerability than with the 'decentralized' version. The issues of vulnerability will be discussed again later. There are two ways of deploying the central processor, namely, in a high orbit or on the ground.

Again each alternative has its own advantages and disadvantages. On the ground the central processor would be easier to control and repair and easier to reach from the command post. But its communications with the battle stations would be more difficult, i.e.,a network of ground-based tracking stations would be required. On the other hand, one space-based station would be enough, if it could be placed in orbit so that it could at all times 'see' the opponent's territory—at the sacrifice of lesser accessibility, however.

Decentralized architecture. This scheme is in many ways preferable but complete decentralization seems to be impossible because of the need to correlate launch detection with the strategic model, as mentioned above. The model would have to be updated regularly, which in any case calls for an intermediate center (perhaps on the ground) to process and incorporate the strategic information coming in from a wide variety of sources. With total decentralization each battle station would have to possess enough computing power to calculate the trajectories of attacking missiles and to assess the strategic information, thus sending the cost of the BMS of a space-based ballistic-missile-defense system sky high. In addition, the communication links between the stations would be extremely complicated, since, whatever the form of the battle-management system, it must function as a comprehensive organized unit, otherwise the BMD as a whole would be ineffective.

Both alternatives are not without weaknesses in terms of vulnerability. A centralized BMS is quite vulnerable at its heart and even stationing it far from the Earth (say at a liberation point) would not guarantee it from destruction by antisatellite weapons, which would then disable the entire ballistic-missile defense. The reliance of the whole of the battle-management system on the central processor makes the latter an exceptionally tempting target—an added impetus for the development of new generations of antisatellite weapons. Some US sources suggest that the vulnerability difficulties can be alleviated by duplicating the central processor station, disguising it, creating fake centers, and so forth.

On the other hand, even the complete decentralization concept of data processing in the surveillance and aiming components still cannot eliminate the need for a center to coordinate the comprehensive defense system, i.e.,there is a certain limit to decentralization. However, the sensors and the command center will communicate using processed and prepared data, which would make the communications more prone to noise (unprocessed data, being generally redundant, are more immune to interference).

Another challenge for a reliable BMS is the target pointing to antimissiles. In the case of laser and particle-beam weapons the problem would be taken care of by a fixed algorithm. But with antimissile projectiles the problem is to share the functions between the guidance system of the projectiles and the station's processor.

The only reasonable answer would be for the central processor to store and continually update 'track files' for targets and their engagement patterns. Proper targeting would require a certain minimum of communications between the station's processor and the guidance systems of the station's antimissiles. But the existence of these communication links, first, makes the control system more vulnerable and, second, adds another level to the hierarchy of the BMS, which imposes further demands on the software and makes its development and debugging more expensive in terms of both time and costs.

To conclude, optimizing a BMS's architecture is fraught with serious difficulties. It involves satisfying conflicting criteria—serviceability, controllability, reliability, survivability, and reasonable cost.

The most likely answer seems to lie in between the architectural antipodes. A 'partial decentralization' concept would itself give rise to serious complications with respect to the degree of decentralization, which in addition to the adove criteria to be met will generate a host of technical issues.

There is another limitation. It is quite clear today that BMS computers would have to be exceedingly fast, but it is unclear whether present speeds of 10^{10} operations per second would be enough for a ballistic-missile defense to identify and work out the trajectories of hundreds of ICBM's in a matter of seconds. This brings us back to the question of architecture, but now of the architecture of the computers employed. Speeds can be increased by improving the computer architecture—say by using data flow processors and various forms of parallel computing systems. These promising architectural schemes are, however, just paper concepts with hosts of uncertainties. And so the developers of the SDI would run into fundamental difficulties since developing an effective battle-management system virtually boils down to developing novel computer technologies. Notice that many of these problems are fundamental (notably developing parallel computational procedures), and it is doubtful that they can be tackled within the short time periods allowed.

5.2.2 Delegation

The need to 'pass the buck' to an automated control center is also rife with difficulties. A remedy is a serious analysis of all the possible errors in the operation of a BMS and of the performance of the sensors.

As far as the sensors are concerned the major task would be to correctly identify the starting ICBM's and to discriminate them from fake launches and interferences, random and deliberate. But the identification could only be confident if the object were recognized from the natural synergy among the various parameters (e.g. size, velocity, exhaust flame temperature, etc.). Information gathered by the sensors of different types would be processed simultaneously, thus piecing together a reliable image of the scene. The existing countermeasures could, however, so affect the BMS sensors that one or more of the data processing channels would be blocked, disabled or made to produce a contradictory signal. This in turn would pose the important question of how decisions are to be made concerning the destruction of the object? Would it be sufficient for one channel of the identification system to fail for the decision to attack the object to be countermanded? Or, should it be two or more channels?

Extrapolating current jamming and interference-producing capabilities suggests that this issue would figure prominently in the design phases of BMD systems. Too low an alert threshold would result in a BMS reacting to signals having nothing to do with a nuclear attack. On the technical side, this would exhaust its resources; on the military and political side, this would mean a nervous and precarious world.

5.2.3 Software

In the early stages of the public discussion of the SDI plans the issue of the development of software for the BMS of the ballistic-missile defense was not in the limelight. Directed-energy weapons, the power requirements of the hypothetical space-based battle stations, etc., provided the grist of the heated debate between the proponents and opponents of the SDI program. How reliable the command-and-control system must be, how difficult the task of developing it would be, and whether errors in the software for a battle-management system could be avoided were dismissed as being of purely technological concern. But as the scientific concepts behind the space weapons were clarified, some of the technological issues, which were overlooked at first, began to come to the fore.

At the present time the interest in the problem of developing reliable software responsible for battle management within the space-based ballistic-missile-defense system has grown. These problems were first highlighted in a report by the Soviet Scientists' Committee for the Defense of Peace Against Nuclear Threat , which precipitated a number of Western publications. These questions became a subject of discussion in the US Senate's Subcommittee on Strategic and Theater Nuclear Forces.

We now turn to some of the technical difficulties in developing battle-management software for a BMS, which appear to be the greatest obstacle to putting the SDI program into effect, and we will also analyze the optimistic prognosis made by proponents of the SDI in respect of software development.

It goes without saying that the main complicating factor here is the enormous volume of the software development effort. It is well known that even small computer programs are only rarely written without errors, and so they as a rule require much time for testing and debugging.

Different estimates of the effort are found in the US literature—from several million to several tens of millions of lines of programming (FORTRAN) code, along with the estimates of the number of possible errors per 1,000 lines—from 300 (clearly, an overestimation) to 0.1. Oddly enough, no arguments were presented in support of either assessment. Doing justice to the traditional American love for figures, we note that it is not only figures that matter here. One error per 1,000 lines—is it many or few? And per 10,000 lines? Ten million lines of code—how is one to assess the effort of writing this?

The questions raised in the US literature do not appear to us to be posed correctly. What is important, of course, is not how many lines there are in a program but how many man-years of skilled labor will be needed to write it. What is also important is not how many errors there will be but what will come about if the software contains at least one error.

At the present time there are some techniques [illegible] for assessing both the size of a program and the possible number of errors in it on the basis of the complexity of the undertaking (by estimating the number of arguments or variables used in the program and the number of results expected). To be sure, this sort of evaluation is only statistical but the many comparisons in [illegible] between predictions and real programs attest to the technique's viability.

Let us now try to arrive at some reasonable estimate of the size of the software-development project for a battle-management system, the size of the operating system in the central-processor version of the BMS, and also the number of possible errors in the resulting software, using Halstead's techniques

Given the total number of independent inputs and outputs η_2^*, the number of operators in a program is found by solving the equations

$$\eta_2 = \eta_2^* \log_2 (\eta_2^*/2)(\eta_1 - 2)/(\eta_2^* + 2) + \eta_2^*,$$

$$(\eta_2^* + 2) \log_2^2 (\eta_2^* + 2) = \lambda(\eta_1 \log_2 \eta_1 + \eta_2 \log_2 \eta_2) \log_2 (\eta_1 + \eta_2),$$

where λ is a parameter characterizing the computer language used (for FORTRAN the mean value is 1.14); η_2 is the number of operands in the program (i.e., the total number of input and output parameters and of intermediate parameters introduced when writing the program); and η_1 is the total number of operators in the program.

The reasons for introducing the variables can be illustrated graphically by comparing the operators in a program to verbs in a conventional language, and the operands to nouns. If then we set η_2^* and λ, then solving equations (5.3) and (5.4) yields η_1 and η_2, and then the total number of symbols in the program (dictionary) $\eta = \eta_1 + \eta_2$ and the length of the program $N = \eta_1 \log_2 \eta_1 + \eta_2 \log_2 \eta_2$. We now proceed to apply this to the task of detecting targets by a BMD battle station.

In principle a station must be designed to be able to engage about 1,000 targets at a range of about 400 kilometers. In order to intercept them the on-board computer would have to compute the location, velocity, the range of each target, and the conditional targeting parameters. We will drastically simplify the problem and seek a lower bound, ignoring all the issues of identification and correlation with the model of strategic situation. We are dealing with the simplest, in the software context, case of the complete decentralization concept, when the computer processor is directly linked to the station's sensors and processes the coordinates of the targets in order to get an accurate fix on them and compute the intercept parameters.

It is clearly desirable that each screen should not contain too many targets. We will suppose that each station has enough screens and each display no more than 20 targets. Even though directed-energy weapons are nearly instantaneous killers, during the split second required for the laser pulse to reach the target the latter will have travelled more than several tens of meters. Since the target has a linear dimension of the order of meters it will be hit even if its velocity is measured with a relatively low accuracy. Further we suppose that several dozen measurements (we put $n = 30$) of the object's locations and velocity will be statistically sufficient to attain the desired accuracy and to choose the optimal timing of the target's engagement.

As noted above, to identify the object several parameters will have to be measured (let $K = 5$). The screen will only show two coordinates for each of the 20 objects. As a result, the total number of the input parameters in the program will be

$$l = 20 \times 2 \times 5 \times 30 = 6{,}000.$$

The number m of output parameters (angular coordinates and ranges of targets) for 20 targets is

$$m = 3 \times 20 = 60.$$

The program parameters will thus total

$$\eta_2^* = 6{,}060.$$

Solving approximately equations (5.3) and (5.4) gives

$$\eta_1 \simeq 0.7 \times 10^6,$$

$$\eta_2 \simeq 0.8 \times 10^7,$$

$$N \simeq 2 \times 10^8.$$

In this limiting case of the simplified situation the software will require an estimated 10 million lines of code (20 symbols per line on average)— twice the sizes of the space-shuttle software or of a major telephone suboffice software in the US public telephone set. Similar assessments are to be found in the US literature for the SDI battle-management software.

Instead of an extremely decentralized processor governing a group of five sensors, we will now assume that all the battle stations are under the control of some integrated software package (as, of course, the case should be). The number of inputs and outputs will then shoot up by a factor of 50:

$$\eta_2^* = 303{,}000,$$
$$\eta_1 \simeq 1.4 \times 10^9,$$
$$\eta_2 \simeq 2.4 \times 10^{10},$$
$$N \simeq 8.4 \times 10^{11}.$$

We thus end up with absolutely unrealistic figures—10 billion lines of code. These assessments illustrate that if developers are to write software of reasonable proportions they would have to use parallel processing to the greatest extent possible.

To gauge the magnitude of such software-development project in terms of man-hours and the number of errors to be expected in programs of that size, we will use the formula

$$\hat{T} = \frac{N^2 \log_2 \dfrac{\eta_1 + \eta_2}{2}}{4S},$$

where N, η_1, η_2 are as above, and S is the Strawt parameter, which varies from 4 to 20.

Equation (5.5) for the first of the cases in question, where $\eta_2^* = 6{,}060$, yields about 10^{12} man-hours of work. The number of errors is given by

$$\hat{B} = \frac{N \log_2 (\eta_1 + \eta_2)}{3{,}000}.$$

For the first case we get 5×10^5 errors. Finding and eliminating so many errors will, of course, require a vast amount of time, perhaps much more than the actual writing of the program package.

The issue of software errors as a criterion of the feasibility of developing a battle-management system suited for the SDI program has of late been a subject of heated debate in the US literature and governmental organizations. The problem was the topic of the statements made at the US Senate's Subcommittee on Strategic and Theater Nuclear Forces by two major US authorities on communications and related software, namely, Dr. D. Cohen and Dr. S. Buchsbaum, two advocates of the SDI program

Consider their reasoning. Cohen rejected the estimates published in *The New York Times* on April 7, 1985, that of 300 errors per 1,000 lines of programming code, and maintained that a realistic assessment is from 0.5 to 3 errors per 1,000 lines of code, and with especially thorough testing and debugging procedures the figure could be as low as 0.1 error per 1,000 lines.

According to Halstead's theory, the frequency of error is sensitive to the program length, growing as the log of the length for large programs.

It follows from the calculations above that for a 10-billion-line software the figure of 60 errors per 1,000 lines is much higher than Cohen's estimate. Applying Halstead's principles shows that the figures quoted by Cohen are only suitable for relatively small software projects. But Cohen's statement contains no reference whatsoever to real BMS software size. Nor does he explain that even with such a seemingly low occurrence of errors in a real BMS program they would run into tens of thousands. Instead he blankly airs his optimism about the feasibility of that huge undertaking. In essence, Cohen ostentatiously employs the rhetorical trick of disproving quantitatively an erroneous newspaper report without bothering to expand on his own statement.

But the cool fact is that even one error in the software (let alone 10^4) might incapacitate a battle station, and hence the entire defense system. At the same time Cohen acknowledged the momentuous problems of developing a software project of the desired proportions, but he was confident that the difficulties could be overcome by the use of the techniques currently employed in telephone communications sets, i.e., fashioning reliable systems out of unreliable components [illegible].

Buchsbaum argued much along the same lines. So he suggested that a battle-management system be regarded as a sort of huge telephone set. Referring to the level of reliability of telephone systems, which are controlled by large software packages containing several million lines of code, Buchsbaum reported that in telephone communications there are debugging methods that come down to duplicating and self-testing elements. On that shaky ground he came to conclusions concerning the feasibility of developing reliable software for a comprehensive space-based ballistic-missile-defense system, although, he admitted, the task is exceedingly difficult.

In fact, there are ideas, due to Shannon and von Neumann [5.28], of fashioning reliable circuits using less reliable elements. Admittedly, such circuits can be developed. A good example is the super-high-speed computer, where the operation of flip-flops is a critical problem. Nowadays we do know of effective means to combat failure in switching devices, a proof of which is the existence of the Cray supercomputer.

Buchsbaum's reference to large systems assembled out of less reliable relays is, however, absolutely irrelevant. The chief stumbling block with battle-management systems is not the reliability of hardware but the reliability of soft-

ware, i.e., the *frequency of algorithmic errors*, which can in no way be reduced to the development of a large system. There is no way at present to safeguard software against algorithmic errors similar to those cited by Buchsbaum. Debugging software is a creative process that requires exceptionally skilled programmers.

The logarithmic growth of the occurrence of errors with program length is an extremely alarming fact, one which can jeopardize the feasibility of writing a program longer than 10^8 lines of programming code. Up until fairly recently the fact has been ignored. It is quite probable that developing software of that size would require a *radically new approach to programming*, and perhaps to the *computer architecture* itself. The human brain successfully handles problems of that caliber, but it seems to be based on absolutely different principles, being essentially a *self-programming* system. Breaking down software into small modules (an algorithm can only be free of errors when the length is no more than 260 symbols) is no answer, since with 10^8 symbols we end up with around 10^6 modules. If we also take into consideration that modular structures, generally speaking, give rise to new inputs and outputs, this approach may eventually become more complex than writing monolithic software.

Now we proceed to estimate the capacity of the operating system that would control the ensemble of computers on the space-based battle stations. As noted above, computers responsible for identifying and correlating tactics with the strategic situation could not be fully self-contained, and so the central processor would have to control the resources of these computers. We may assume that the number of controlled resources R_a is equal to that of the sensor stations, then the number of commands in the software will be (see)

$$P = \frac{3}{8}(R_a - 1)2^{R_a}.$$

It is easily seen that the number of resources of the operating system cannot exceed thirty, otherwise the commands in the system will total 10^{10}, and such a system can hardly be written.

At the same time 30 sensors are scarcely enough for an effective ballistic-missile defense.

The difficulties analyzed by the Soviet Scientists' Committee could be alleviated by constructing a battle-management system with an operating system based on an hierarchy of control stations. In addition to a global battle-management system with a central processor there would be a set of intermediate stations, each controlling 20–30 sensors surveying the strategic landscape. An impermeable space-based ballistic-missile defense presupposes constant monitoring of the opponent's territory, hence a constellation of 200–300 sensors, and about 10 intermediate control stations would be required. This battle-management system architecture would obviously make the space-based components even more vulnerable, since destruction of some of the intermediate stations would, even with a measure of redundancy, produce a 'window' in the BMD system, thus making it vulnerable as a whole.

5.3 Conclusion

One important feature of a battle-management system is the need to incorporate into it not only purely technical characteristics of prospective targets but also elements of the general strategic background against which the decision to involve the BMD can be made. The decisions would have to be made almost instantaneously, decisions based on a host of strategic, tactical, technical, and political considerations—an unprecedented task. Clearly, a battle-management system should as a minimum have a reflective model of perception of the political and military situation by the opponent along with a model of the opponent's decision-making machinery in military and political matters. At present these issues are in early development stages even on the theoretical side. As mentioned above, it has been stressed in some US reports that the battle-management system of a ballistic-missile defense should be an *expert system* of enormous proportions, i.e.,an artificial intelligence system embodying expertise, assessments of military and political situations, and predictions of their future development. But the research and development of that kind of expert system has only just got off the ground, and the outcome of these investigations is still tenuous. Also, one should not overlook the fact that such an expert system, and hence the dominating logic of the battle-management system, would in the first place be a product of the psychology and thinking of those in the military and political leadership who would be directly involved in the development of the system.

The advocates of the Strategic Defense Initiative primarily belong to those military, industrial, political and academic circles in the United States which hold extremely negative, almost paranoic, perceptions of the Soviet Union's plans, and are among those most ready to resort to military force in conflict situations.

If then we remember that a space-based ballistic-missile defense would be forced to function under tight time constraints with a minimal amount of human intervention, the above-mentioned features of its artificial intelligence could under certain circumstances be fatal.

Because of the unparalleled complexity of the software and the intra- and inter-componental links, the battle-management system is likely to have inherent in it a large measure of internal instability. It would be safe to suggest then that certain, however slight, random disturbance might suddenly activate the orbital battle stations. The activation of a BMD system might be regarded by the other side as a preparation to fend off a weakened retaliatory strike after the possessor of the BMD had inflicted a nuclear first strike using its ICBM's, SLBM's, MRBM's and long-range cruise missiles. The situation might go completely out of control because the BMD system and the anti-BMD system would form together an automatic macrosystem that cannot inherently be optimized or tested. Optimization and tests would only be possible with an open exchange of information and joint measures. Since such an opportunity does not exist, the probability of er-

roneous commands in the macrosystem would be much higher than in common automatic systems.

There are a number of fundamental questions that cannot be answered by today's technology. For instance, as it has been noted, there can be no check on the entire ballistic-missile system 'from top to bottom' under conditions that would completely simulate a war-time situation. Unlike the air defense systems of the last war, which were improved with experience, a space-based ballistic-missile defense would have to function perfectly from the very beginning.

Concern has arisen that the proposed system would, most likely, be triggered automatically, because it would allow no time for decision making by responsible humans (there would be only half-minute warning if an attacking nation unleashed its fast-burn ICBM force).

There are attempts to class the SDI project with large-scale complicated technical programs, such as the Manhattan Project (the development of the A-bomb) or the Apollo Project (landing a man on the Moon). One radical departure of the SDI is that now the scientific community would confront not only the laws of nature, which can be understood and which remain unchanged, but also an astute opponent, who can and will unpredictably use the same laws against the originators of the BMD.

Intuitively, many 'average Americans' entertain a hope that in the course of realization of the SDI program some technological 'miracle' will come about, such that all the teething troubles which the strong opposition is now decrying will disappear overnight. Another example of popular delusion. Admittedly, a 'miracle' or a technological advance cannot be excluded, but it would only be able to provide an impetus to one of the many gray areas of the comprehensive space-based ballistic-missile-defense system. Moreover, it is equally likely that the 'miracle' will be used by the other side with the same or even greater effect.

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Chapter 6
Countermeasures

The main goal of countermeasures would be to retain retaliatory capabilities sufficient to destroy the aggressor. It is in this context that US observers consider possible reactions to the deployment of a space-based BMD system using retaliatory strike scenarios.

There could be active and passive countermeasures. The former would be based on the development of means for neutralizing and destroying the various components of a multilayered BMD, and the latter on the buildup, modification, and diversification of strategic offensive nuclear forces.

It is quite obvious that the countermeasures will only be identified conclusively after the BMD picture has been established and its capabilities assessed with respect to ICBM interception and its threat to ground and air-borne targets. It is also obvious, however, that even now some local means are feasible from the technological and military points of view. They could be used to strike against such vital and quite vulnerable BMD components as:

— space communications, which could be disrupted, jammed or even totally disabled;
— battle-management system, whose most vulnerable element is the central processor, which even with redundancy could only be deployed in a limited number of units because of complexity and costs;
— energy carrier and power systems (nuclear-power plants, explosives, fuels, other combustibles) [6.1–6.3].

6.1 Destroying and neutralizing countermeasures

Active countermeasures of this kind include a wide variety of ground-, sea-, air-, and space-based weapons using the kinetic-energy concept (rockets, fragments, etc.), lasers, and other high-energy radiations. These countermeasures are especially effective against space-based components, which stay for a long time in their orbits with known parameters making them easy to neutralize, overwhelm and even to destroy.

So, there is a wide range of active countermeasures against a constellation of battle stations deployed in space. Since the main mission of the battle stations would be the destruction of ICBM's, small rockets of various basing, adequately disguised, will be efficacious means for destroying the stations [illegible]. The rockets would clearly have fast-burn boosters to minimize their boost phase. They too would have to be shielded against high-power radiations. Rockets of that kind are already available. Take for example the fast-burn Sprint antimissiles, which are capable of withstanding high aerodynamic and thermal loads in the dense atmosphere.

Another good way of simultaneously putting out of action several stations would be to use the so-called 'space mines,' which are essentially satellites with high-yield explosives placed into orbits close to the opponent's battle stations, which explode on command from the ground. The mines could be supplied with all sorts of fuzes, in particular mechanical- or thermal-actuated ones.

Other active countermeasures are ground-based high-power lasers. These lasers are much simpler to deploy than those that are proposed as space-based weapons against ICBM's in the boost phase. The 'countermeasure' lasers are also more effective for a number of reasons. First, space battle stations are larger targets than ballistic missiles; second, there will be fewer battle stations than attacking ICBM's to be dealt with in a massive launch and flight; third, the stations would stay within the field of sight of a ground-based laser facility for a long time, thus enabling longer dwell times (up to 10^3 s) and hence reducing the demand on their power supplies. Furthermore, ground-based lasers are not subject to stringent requirements on mass, overall size, energy resources, efficiency, and so on.

Still other active countermeasures are swarms of small pellets ('space shrapnel') travelling with a relative (to a satellite) velocity of 15 km s^{-1}. In a head-on collision a 30-g particle hitting the satellite at that velocity can pierce a 15-cm steel shield (or the satellite's skin). The most vulnerable components of a battle station are fuel compartments, power units, mirrors. A small cloud of microparticles produced in orbit may cause defects on the surface of the reflecting mirror that will make laser-beam focusing impossible [illegible].

In the case of the scheme using ground-based excimer lasers and mirrors in a geostationary and low orbits, another effective countermeasure is dispersing materials that are strong absorbents of the laser radiation near the laser or the mirror.

As for countermeasures against nuclear-bomb-pumped X-ray lasers, one should take into consideration the following. One of the SDI concepts ('pop-up scheme') presupposes putting these lasers into orbit on the spur of the moment using SLBM's. The SLBM submarines would patrol the World Ocean as close to the USSR as possible (the scheme rules out launches from US territory because this would require long times for the pop-up antimissiles to reach altitudes op-

timal from the point of view of destroying attacking ICBM's by X-ray laser). It has been estimated that even the most powerful boosters could not 'pop-up' an X-ray laser from US territory to the required altitude (3,000 km) by the end of the boost phase of the launched ICBM's. The only answer would, therefore, be to deploy the submarines in the northern part of the Indian Ocean or in the Norwegian Sea . Clearly, the scheme would be rather vulnerable to antisubmarine facilities, which the other side would deploy adequately.

The task of hunter-killers in that case would present no particular difficulties. Also, no special-purpose means of antisubmarine warfare would be required.

Another fairly vulnerable element of a BMD is the system of surveillance, acquisition, and tracking. It can be blacked out by a nuclear blast in the upper atmosphere. Lastly, the traditional methods of jamming, which have been actively worked on for decades now, when applied against the space-based component of the BMD, could drastically reduce the efficiency of the surveillance, acquisition, and tracking system, or even put it out of action completely.

This brief overview of the possible active countermeasures against a wide-scale space-based ballistic-missile defense shows that it is not necessary at all to seek its total destruction. It is sufficient to weaken this 'macrosystem' by attacking its especially vulnerable elements, to break a 'hole' in it so as to make it ineffective against the attacking ballistic missiles [6.7].

6.2 Buildup of strategic nuclear forces

Hypothetic countermeasures may also include the buildup of strategic nuclear forces, above all, the increase in the *number of ICBM's* and of the so-called '*fake ICBM's*.' The proposed US deployment of a space-based ballistic-missile defense or its individual components is a direct violation of the ABM Treaty of 1972. It is only natural that should the SDI plans be pursued, the USSR would be forced in the interests of its security to denounce its commitments pursuant to Article XII of the Treaty, which bans deliberate concealment measures which impede verification by national technical means, and to the SALT II Treaty (not ratified by the USA), which limits the number of ICBM's and construction of new ICBM launch sites.

The quantitative buildup of ICBM arsenals, and hence of retaliatory capabilities, will exacerbate the problem of acquisition and identification for a BMD system, thus affecting its interception capabilities. This will increase the 'penetrability' of ICBM's and decrease the reliability of a 'space shield.'

Similar results are obtained by having *more warheads* on MIRV'd ballistic missiles. This countermeasure can compensate for the ICBM's lost in the boost phase of their trajectory by 'saturating' the BMD with targets that the system will have to handle later in the trajectory.

Further 'saturation' can be achieved by deploying relatively cheap unarmed 'fake ICBM's' with a simple guidance system. These 'fake ICBM's,' which cannot be reliably identified by today's means, will be a simple and cost-effective countermeasure (compared with the staggering costs of the proposed BMD), which will degrade the defense by making it waste its defensive resources, above all, in the boost phase, which figures prominently in the SDI concept.

Another countermeasure is *ICBM launch tactics*, such that will 'deplete' the resources of a space-based ballistic-missile defense by forcing it to 'bleed white' when confronted with unpredictable timing of an ICBM strike. For instance, the possible patterns may be joint launches of real ICBM's and fake ICBM's, launches with various lofted and depressed forms of trajectories, launches in various directions, and so on and so forth. This will impose yet another power demand on the space-based BMD component and will make the defense squander its resources, e.g.,due to the need to retarget quickly the weapons in a disorderly manner. Consequently, the defense can be nullified.

To retain its retaliatory capabilities, the other side will be tempted to build up *such strategic weapons that are so far relatively invulnerable to interception*. Above all, these are submarine-launched ballistic missiles with depressed trajectories. Most of these SLBM's trajectory is within the endosphere, where current ABM defense systems are ineffective. Another answer may be the *massive deployment of cruise missiles* of different basing mode. None of the proposed versions of space-based BMD is capable of reliably detecting and hitting a low-flying small cruise missile with low radar cross-section. Handling thousands of differently based long-range cruise missiles will be a formidable challenge solved at formidable costs.

One passive measure aimed at improving the survivability of ICBM's is *shortening their burn-out times*, i.e.,times in the boost phase. Boost-phase parameters of today's ICBM's are chosen such that the overloads be minimal and the trajectory be optimal in terms of fuel consumption. The experts on Fletcher's panel noted that it would be possible to have burn-out times as short as 40 s and burn-out altitudes as low as 80 km. According to their estimates, these figures could be achieved at a relatively low cost with launch masses increased by about 15 per cent and the payload and range retained. Shorter boost phases will mean tighter timing constraints on the systems of surveillance, acquisition, tracking, and kill assessment, and hence lower efficiency of the BMD as a whole.

Other countermeasures to boost-phase defense can be broadly divided into two groups: measures to impede the targeting of the antimissile weapons and countermeasures to protect boosters. The first group includes *changing the brightness and configuration of the exhaust plume* of an ICBM. To be sure, the target is not the plume itself, but the missile located several meters above it, and so any infrared-guidance system would use aiming algorithms to fix the missile

relative to the plume. Furthermore, the laser beam would be allowed to dwell several seconds on a small aim point. Accordingly, changing the brightness and geometry of the plume will impede aiming and holding the beam, since the changes, sensed by infrared detectors, will cause the beam to shift following the algorithm used. The required instabilities of the plume can be obtained using various additives to propellant.

Another countermeasure in this group is *concealment*. It can be realized either by the use of smoke screens over launch sites or by the use of a variety of deception means to disguise an ICBM in flight, e.g.,camouflage screens.

There are also many *protective countermeasures against laser radiation*. They include protecting the missile body with reflective or ablative coatings, and rotating the missile about its central axis to stop the beam from concentrating at one spot on the booster. The booster of a missile can also be equipped with a cooling system or a moving absorbing screen. So a 1-cm graphite coating will be sufficient to absorb an energy deposition of 200 MJ m^{-2}. The aerosol dispersal of various substances in the atmosphere for the absorption of laser radiation is another promising countermeasure. Perhaps it will pay to return to the constructions of the early rockets. Say, the German V-2 had its fuel and oxidizer compartments tucked within the pressure shell of the body. Doing away with the load-carrying structures of the compartments and returning to the two-loop double-walled structures of compartments could increase ICBM's resistance to laser radiation.

Various combinations of these and other countermeasures will appreciably reduce the vulnerability of ballistic missiles in the boost phase of their trajectories, and the more ICBM's that survived in this phase, the more difficult it would be to intercept them later in the trajectory. Passive countermeasures are also possible throughout the midcourse phase. Sometimes midcourse is thought as including two subphases, the first being the post-boost subphase before the bus has released all the warheads and decoys, the second is free flight of the 'threat cloud' until the reentry, or terminal phase.

The post-boost, or 'busing,' part is more convenient for interception, because there are fewer targets to be intercepted. But a missile can burn out while still in the atmosphere with *an earlier separation of the bus and simultaneous clustering of warheads*, and so some experts believe that midcourse is to be regarded as a 'threat cloud' phase. The long duration of this phase (20 min or more for ICBM's and about 10 min for MRBM's) offers more possibilities for interception. What is more, in this phase the longer expositions of warheads possible both to individual weapons and to the various combinations of them sort of compensate, as compared with the booster, for the higher hardness of warheads.

On the other hand, in this phase the antimissile weapons have more targets to be identified and intercepted, whose number in a massive attack may reach

tens of thousands. All of these targets, both warheads and decoys, travel with essentially the same velocity in the same ballistic trajectory. And so the main difficulty here is the stringent constraints imposed on the systems of surveillance, acquisition, tracking, and kill assessment, which become especially pressing if the massive strike was not sufficiently weakened in the previous phases.

These two important considerations lead one to conclude that in this phase passive countermeasures should be used, that is those directed against the tracking and aiming components of the ballistic-missile defense. In this phase it is especially difficult to sort out warheads because, in addition to being too numerous, the targets in the 'threat cloud' are small and have no rocket plumes.

Midcourse sensors use a wide variety of active and passive principles (optical, infrared, radar, etc.), they may be ground-, air-, or space-based. All of them are vulnerable to the countermeasures mentioned above. Besides, many other midcourse countermeasures can be developed.

As noted many times above, effective countermeasures are decoys of sorts. For example, when the bus releases MIRV's, they are generally surrounded by a cloud of *radar-reflecting wires* called *chaff*, or a cloud of *infrared-emitting aerosols*, which are a good countermeasure to infrared sensors and guidance systems. Against this background it is possible to disguise the infrared radiation of a warhead. These countermeasures are all fairly effective and, what is also important, inexpensive and accessible.

The sensors of a space-based ballistic-missile defense can be overwhelmed by all manner of *electronic interferences*, *jamming and distortion of signals*, and by fitting the decoys with *devices mimicking the reflection from warheads of laser, radar or optical signals*. It has already been mentioned that warheads can be camouflaged within light-weight multilayer empty balloons made from a metallized reflecting film. For each warhead within a balloon there may be a dozen empty balloons. What is important here is that it is possible, in addition to the indistinguishability of 'filled' and 'empty' balloons from the signatures of the signals reflected from them, to make them also identical in their ballistic coefficients [6.5–6.7].

The countermeasures just discussed clearly do not exhaust the midcourse countermeasure capabilities against the acquisition and aiming systems of a BMD.

In the terminal phase (on reentry), the decoys will lag behind the warheads due to differences in mass and aerodynamics, which makes them easier to sort out. But this phase is short (under 60 s), which calls for exceedingly fast interceptors. Interception here can be countered by making the high-velocity warheads manoeuvrable. It is also possible to use higher-yield explosives and salvage-fuzed warheads. It was estimated that in this case, even if a warhead were to be detonated at a height of over 10 km, the destructive effect would be significant.* To be sure, the realization of these countermeasures imposes some demands on the respective sides, e.g., ICBM's will have to be heavier and hence the payload

lower. But these losses can be compensated for by a quantitative buildup of ICBM's. But on the whole, the answer to these problems lies well within today's technological capabilities.

Some of the SDI advocates envision the multilayered structure of a BMD as fairly insensitive to 'leakages' through some of its layers. Their proofs are generally based on elementary computations of the probability of penetrating these layers that are based on the false premise that the layers function independently and fail to include the diversity of possible countermeasures. That this approach is wrong can be illustrated best of all by countermeasures to such an element of the BMD as battle management (surveillance, acquisition, tracking, and kill assessment). Since the various layers of a space-based ballistic-missile-defense system are interdependent, being guided by the general battle-management system, it is clear that damaging this most important structural element of the BMD can cripple the entire defense.

Thus we can now say with a certain degree of confidence that it would be impossible to achieve impenetrability of an antiballistic missile 'shield.' There is a large tool kit of effective, accessible, inexpensive means which the other side can deploy in order to retain its retaliatory capabilities at a sufficiently high level. Analysis shows that a BMD system should be considered offensive since it would be effective only if the side in possession of the BMD strikes first.

A number of investigations conducted by the Soviet Scientists' Committee using both general and special techniques of systems analysis yield one overall conclusion regarding the strategic balance. In fact, various combinations of countermeasures we have discussed eliminate the danger of the unilateral breach of the strategic parity that would occur if a BMD is deployed. Moreover, the countermeasures would be significantly cheaper than an antimissile arsenal in space. One of the cost estimations revealed that countermeasures would be only a few per cent of the cost of the proposed space-based BMD.

In summary, one of the hazards of the deployment of such a BMD is that it provokes the other side to build up its strategic forces and countermeasure facilities with all the negative implications for international security.

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Chapter 7
Strategic and political aspects

7.1 General

A space-based antimissile system, even if ideal from the scientific and technological points of view, would never accomplish, as is contended by some members of the US political leadership, a 'turn around' in strategic thinking to substitute the deterrence based on the concept of 'mutual assured destruction,' by the deterrence based on the concept of 'mutual assured survival,' since it would not guarantee total protection from ballistic missiles and space-based strike weapons. Therefore, all the arguments in favor of the allegedly stabilizing role of comprehensive BMD make no sense. It is also worth emphasizing that concurrently with the deployment of the SDI plans, the US is actively pursuing a program of deployment of strategic offensive arms, nuclear medium range forces, and theater nuclear arms. Consequently, the development and deployment of a space-based BMD would only complicate the issue of mutual deterrence and would lead to a more precarious strategic balance.

Such a view of the proposed US antimissile system as a way to enhance the country's first-strike capabilities is also determined by the fact that the US is not willing to commit itself not to use nuclear arms first, and continues to build up its first-strike capability. One important element of this policy is the deployment in Europe of US medium range nuclear-armed missiles, notably Pershing 2 rockets.

It would be pertinent to recall in this connection that the USSR, cognizant of the importance of enhancing stability of the balance considering the tenser military and political situation, announced unilaterally in June of 1982 that it would not use nuclear arms first.

Drawing on past experience one can assume with a high degree of probability that the development of a BMD would cause the deployment of a host of countermeasures to thwart the threat posed by it.* One can agree with those experts who believe that as a BMD would be developed and deployed, so would the countermeasures. Also the BMD would be a strong incentive for the buildup of strategic nuclear arsenals—both delivery means and warheads—in particular of air-, sea- and ground-based long-range cruise missiles, whose deployment is *inter alia* hardly amenable to control by national technical means.

As noted in Chapter 6, one of the possible countermeasures would be to use depressed trajectories for SLMB's. This response would, in turn, be interpreted by the American side as a threat to the bomber 'leg' of the strategic 'triad,' since this would imply shorter times needed for SLBM's to strike at strategic bomber bases. A comprehensive BMD would thus disturb the synergy of the triad structure of the strategic nuclear forces, which in the opinion of US military planners is an important factor in the stability of these forces.

Space-based antimissile weapons can, with good reason, be viewed as having antisatellite capabilities [illegible]. And this is bound to undermine the balance within the macrosystem of strategic relations, since the balance is in many respects determined by the degree of faith placed by the sides in the reliability of their respective surveillance and early warning satellites.

A decision to intercept a satellite in space (using nonnuclear means, of course) is clearly easier to make than a decision to use military force directly against another country. Such an action may, however, trigger a conflict which may escalate confrontation to direct hostilities, from regional to global and from conventional to nuclear levels.

This stems specifically from the fact that antisatellite operations cannot, by virtue of the laws of astrodynamics, be localized (by the distribution of the targets and the weapons) and will immediately become global. An antisatellite operation might suddenly develop into attacks at the most vulnerable components, such as satellite communications and control facilities deployed on the ground and at sea all over the world, and these attacks could hardly be confined to conventional arms. The chain reaction of destroying the satellite systems, along with other measures of disrupting the command, control and communications systems would quickly render the situation uncontrollable; thus disrupting the links between the national leaders and the forces in the field and the nation at large, and as the uncertainties of the situation would be intensified, the probability of a fatal mistake and unwarranted response would increase. On top of that antisatellite actions would affect the space-based communications with strategic forces—the 'best' way of initiating a nuclear exhange.

A systems analysis of the stability of the strategic balance with the above inputs shows that, contrary to what the SDI advocates say, should both sides have comprehensive BMD's, instability would grow, especially considering the wide variety of countermeasures (discussed in Chapter 6) and the vulnerability of BMD's components.

One should emphasize that the so-called defensive space-based weapons that are planned for development in the US could in actual fact be employed not only to strike against the other side's satellites and ICBM's in flight, but also as a first-strike weapon against ground and air targets of an opponent.* These weapons would be of special danger for countries that are unable, for economic, technological or territorial reasons, to install adequate countermeasures against

the threat from space, as are able the USSR and its allies in the Warsaw Treaty Organization, which might enhance antagonism in the world.

The SDI program is especially dangerous because it appeals to the psychologically natural human desire to find at last some sort of protection against the awesome destructive power of modern nuclear weapons. The advocates of the Strategic Defense Initiative expertly cash in on this feeling.

The same goal is pursued by some Western strategic planners who argue that, in compliance with the dialectics of the evolution of warfare concepts, the predominantly offensive warfare of the past centuries must be replaced by a predominantly defensive warfare of the future, and nuclear weapons, which have underlined the military doctrines of the last few decades, must in turn be replaced by some fundamentally new weapons, in this case, by the directed-energy weapons.

It is worth noting here that any references to the dialectics of warfare concepts (which by the way has been given the best treatment by F. Engels in *Anti-Düring* and by other classics of Marxism) is irrelevant in the case of a space-based ballistic-missile defense. Actually, the struggle between offense and defense throughout history occurred with varying success. In the long run, the general tendency seems to have been for the civilian population to suffer ever increasingly from the horrors and destruction of wars. Recall World War I, a classic example of the predominance of defense, which predetermined its trench warfare tactics but involved a then-unheard-of scale of destruction over enormous areas in the war zone (Marne, Verdun-sur-Meuse, Galicia, etc.). Nuclear weapons stand out in this respect as weapons specially designed and first used by the US for massive destruction of civilian populations and material assets. The prospect of total destruction of peaceful civilians and devastation of enormous areas has always overshadowed any attempts of Western strategists to invent some ways of using these weapons to solve military missions, to inflict 'limited' and 'selective' strikes.

The SDI proponents in the US lean heavily on the thesis that, as compared with the late 1960s and early 1970s when the US–Soviet ABM Treaty (of unlimited duration) was negotiated, there have now appeared new technologies that change the situation between offense and defense in the nuclear age. This thesis is used as a basis for far-reaching conclusions of technological, political, and military character.

Among the latest breakthroughs in science and technology that allegedly offer unprecedented defensive capabilities are mentioned advances in the hardware and software branches of computer technology (faster speeds, microminiaturization, artificial intelligence elements, etc.), sensor technology, laser technology, neutral particle accelerators, electrodynamical mass accelerators, new generation of hefty boosters. In these and other fields of technology, as noted in earlier chapters, substantial strides have really been made as compared with the

end of the 1960s and beginning of 1970s. It is to be stressed, however, that considering the rich variety of elements in a hypothetical BMD, advances in individual areas provide no solution to the problem as a whole.

Many US sources, including the Government, admit that as of now and in the foreseeable future, these achievements are clearly insufficient to create a full-scale space-based ballistic-missile defense. Furthermore, the fashioning of a widely distributed macrosystem, with a tangle of links, out of individual components (detection, recognition, aiming, battle management, weapons, etc.) is a fundamentally new, exceedingly complex task.

Publicizing the defense-dominated world, a world that is only possible due to the high level of sophistication of the current technologies, the sources pass over in silence the fact that the same technological capabilities might, perhaps even with more success, be used to create effective countermeasures (see Chapter 6). On the other hand, offensive capabilities have in the last 10–15 years grown as well, mostly due to US initiative. Worthy of special mention are MIRV'd missiles, long-range cruise missiles, and new highly accurate guidance systems for delivery vehicles. The development of a new generation of SLBM's is nearing conclusion in the US. These sea-launched missiles will be compatible with land-based ICBM's in their destructive power.

Notice that expatiating about dazzling prospects of antimissile technologies, the SDI officials 'forget' to mention the prospects of development within the same time scale of offensive technologies, which could clearly make spectacular progress. These could include, as noted above, making MIRV's on ICBM's and other vehicle manoeuvrable, converting SLBM's to depressed trajectories, using more decoys and fast-burn boosters, and so on and so forth.

Comparison of the evolutions of defensive and offensive technologies puts in question any prospects of a defensive system gaining some advantage. Moreover, since the offensive and defensive strands are intertwined, should the SDI plans be pursued, it would become necessary, and hence possible to develop a new class of weapons specially designed to degrade and nullify a BMD, first of all its space-based components. Many technical means suitable for solving such problems are in such high development stages in the US itself, that, according to some US experts, they could be realized much faster and cheaper than a comprehensive space-based ballistic-missile defense. In addition, many Western observers maintain that initiating major SDI programs in a tense international climate would spur the development of those mass destruction arms which are beyond the capabilities of a BMD. In view of this, it is apparently not by chance that parallel with the discussion of the SDI plans, US military planners raised the question of the need of working out alternative measures against a potential Soviet BMD (it has been repeatedly stressed by Soviet government officials, in-

cluding the USSR Minister of Defense Marshal S.L.Sokolov, that the USSR does not work in this area [7.2]).

Of course, there are some military R&D programs in the USSR, but they do not aim at developing space-based weapons. Their objectives are improving space-based early-warning, reconnaissance, communications, and navigation satellites.

There are no preparations in the USSR to deploy a nation-wide BMD based on air-defense facilities, and no programs that could violate the ABM Treaty of 1972 in general are under way.

Much coverage in Western mass media was given to the construction of a radar site near Krasnoyarsk, in Siberia. It was contended that this radar is an early-warning radar against ICBM's and is being constructed in violation of the Treaty.

Official Soviet spokesmen explained that the radar is designed to carry out observations of space objects. The Agreed Statements regarding the 1972 Treaty stipulate that the limitations on the potential of phased-array radars do not include the radars used 'for the purpose of tracking objects in outer space or for use as national technical means of verification.' Therefore, the Krasnoyarsk facility is not in violation of the Treaty.

Even if in the foreseeable future US–Soviet relations improve so that the American side will be prepared to negotiate mutually acceptable and equitable constraints on strategic arsenals, then even the limited presence of tested and deployed components of a space-based ballistic-missile defense would markedly complicate negotiations and drastically curtail the chance of achieving such agreements. That this is really so is confirmed by the practice of negotiating SALT I and SALT II. Without the ABM Treaty, they would simply have been unthinkable [illegible]. The legal issues of the SDI plans are considered in more detail in Chapter 8.

Introducing into the strategic equation a further radically new and all-important component, such as a comprehensive BMD, would confuse the entire system of assessing the strategic balance and would worsen the international climate.

Things might be entangled even more, if one takes into consideration the inevitable countermeasures of the other side, including those directed against the space-based component of the proposed BMD, respective counter-countermeasures, and on indefinitely—a vicious circle so familiar to the designers of weapons.

The experience of the last decades has repeatedly proved that the USSR will not allow any shifts in the balance. Whatever the US moves, the balance will be restored, albeit at a higher level. The future world will thus be a world of more nuclear warheads aimed by the sides at each other, of shorter times allowed for making fatal decisions, of higher risks of nuclear war.

The development of military technologies, the 'action-counteraction' cycles in the arms race can make the course of events irreversible. Looking back at the arms race of the past decades, one cannot help regretting many 'initiatives.' Only some of them have been reversed, at great cost.

Can the arms race in space be prevented? There is a deep conviction on the part of the Soviet Union that there are possibilities yet, they rely on a solid foundation of international law, which contains many pertinent agreements (see Chapter 8).

One other political implication of the deployment by the USA of a space-based ballistic-missile-defense system is the fact that it would be in the way of US–Soviet cooperation in the uses of space for peaceful purposes. Scientifically and economically, this cooperation would be quite valuable, since the space programs of the USA and USSR are in many respects complementary. The political importance of such a cooperation would be immense, especially for US–Soviet relations and for building confidence between the peoples of the two great countries.

Should the world community find overhead in near-earth orbits offensive and antisatellite weapons, the 'space for peace' programs, from which humanity at large could benefit enormously, would be in jeopardy.

7.2 The strategic balance

The modern military and political landscape is characterized by a strategic parity reached between the USA and the USSR. The strategic parity is an important condition for maintaining strategic stability, especially if it provides mutual ability of both sides to launch assured retaliatory strikes inflicting unacceptable damage. Such a state of affairs has proved to possess a measure of stability, notwithstanding the significant difference in the geostrategic position of the sides, the asymmetry in the structure of their nuclear forces, and the differences in the characteristics of their weapon systems.

In an attempt to break away from the nuclear blind alley and gain strategic superiority, the USA spurted ahead in the 1960s in the arms race, and in the 1970s tried repeatedly to tip the balance in its favor. Nevertheless, late in the 1960s the USSR answered with an increase in its strategic arsenal, and despite the American efforts, it managed to restore the parity. By the mid-1980s, owing to counter steps taken by the USSR, the strategic equilibrium became more stable and balanced [illegible]. It is now more difficult than ever before to disrupt the parity (by increasing and improving nuclear forces), to establish supremacy of importance in military, political, and diplomatic respects.

This margin of strength, inherent in the attained parity, is determined by a multitude of factors, one of them being the very nature of nuclear weapons, i.e.,its enormous destructive force, lethality, especially against cities, industrial objects, ports, and major military bases. A relatively small number of nuclear

warheads (hundreds out of the 50,000 now in existence) are capable of killing and maiming millions of people, destroying the economies of major nations.

The stability of the balance is ensured also by the variety of complementary ingredients in the strategic forces of each side, which include land-based ICBM's, sea-based SLBM's, strategic bomber forces. The presence of the synergy of the three 'legs' of the strategic 'triads' of the USA and the USSR is one of the most important deterrents of first strikes capable of eliminating or markedly weakening retaliatory second strikes. Both sides are capable to launch a retaliatory strike inflicting unacceptable damage, this capability being due to adequate, multiply duplicated systems of early warning about a nuclear missile attack, and of command, control and communications; both sides' strategic forces are maintained at a high level of combat readiness.

These and other circumstances, now that the world has accumulated enormous arsenals of nuclear weapons, make the entire system of the nuclear strategic balance relatively stable despite some technical differences in the nuclear weapons of both sides. Of course, one should not overestimate the degree of stability of the balance, which is essentially the 'balance of terror,' both military and political. The stability, even with the countermeasures taken by the USSR, may be undermined by the year 2000 because of the nuclear arms race enforced by the American side whose aim is to gain unilateral first-strike capabilities ...

The 'balance of terror' is a precarious balance. A really secure and peaceful world is only possible when both sides (and any other nations) have no nuclear arms. The world would be much safer if it were free of nuclear weapons and respective delivery vehicles, if all conflicts were tackled by negotiations, if economic, scientific and cultural international cooperation were improved and expanded.

Instead, some powerful groups in the USA, notably in the military-industrial complex, would like to offer the world at large a vicious way of ensuring safety—by creating a comprehensive space-based ballistic-missile-defense system.

The problem of protection from nuclear weapons made its appearance together with nuclear weapons, and the major difficulties here were perceived as early as in the 1940s.

In 1945 R. Oppenheimer noted the exceptional role of nuclear weapons, the inability of the then-technology to install effective countermeasures, and the need for a search for political solutions to the problem of international security.

During the past three decades, arguments more or less similar to those of Oppenheimer had in various situations been echoed by many scientists, statesmen, and politicians. What then is behind the predominance of offense over defense in the nuclear age?

This stems once again from the momentous destructive force of nuclear weapons. With the advent of these weapons, the age-old confrontation of offense

('sword') and defense ('shield') reached a level beyond which offensive weapon capabilities increased by jumps, in an unprecedented manner. For the strategic forces of one side to be able to inflict unacceptable destruction to the other side in a retaliatory strike, their effectiveness, measured as the ratio of the number of warheads that reach their destinations to their initial number, can be as low as 1 per cent or even less.

Consequently, in our day a 'shield' capable of fending off 99 per cent of the accumulated nuclear arsenals makes no sense. The 'leaked' one per cent would be sufficient to destroy our civilization. The defensive systems must be very nearly 100 per cent effective. This unavoidable discrepancy in the required effectiveness of offensive and defensive strategic systems is independent of the level of technological progress, since both types of systems develop in the same technological medium, and the advances of scientific and technological progress will be used equally in ballistic-missile defenses and in offensive strategic arsenals.

The statement that in our times offensive systems inherently predominate may seem to be unproved, but it is inferred from a detailed analysis of all the hypothetical antimissile defenses suggested earlier. There are no grounds to doubt that the advantage of offensive nuclear strategic forces will never be overcome by the new BMD's envisioned within the framework of the Strategic Defense Initiative. Taking into account the host of problems presented by the SDI program and discussed in other chapters of the book, we can note the following:

1. The new version of an ABM defense would rely on space-based elements, which include both combat components and support components (detection, indentification and targeting, battle management, and so on). As noted above, these components would be more vulnerable to countermeasures than ICBM's, because they would be in known orbits, there would be fewer of them than the ICBM's, MIRV's and decoys.
2. Even if today's ICBM's and SLBM's appear to be vulnerable to the new hypothetical weapons of the proposed BMD, then even now the main directions for modernizing offensive systems are quite apparent. Moreover, such a modernization would not require any revolutionary methods.
3. The development and deployment of a space-based ballistic-missile defense is bound, sooner or later, to bring about a dramatic improvement and massive increase of offensive weapons on both sides.

Even some of the SDI advocates are forced to admit the momentous, unparalleled technical problems that would be encountered by the developers of a BMD. This is also obvious from the changed tenor of their statements. Whereas in President Reagan's speech of March 23, 1983, which marked the beginning of the SDI, and in some other subsequent reports, the deployment of a comprehensive BMD was viewed as an alternative to the world of mutual deterrence, in the latest

statements of SDI advocates one more often sees recognitions that in the foreseeable future nuclear weapons will coexist with antimissile weapons, and the strategic balance will still rely on the 'mutual assured destruction' concept. At the same time, it is recognized to some degree that the most important conditions of the development of a comprehensive ballistic-missile-defense system are its survivability and cost-effectiveness. These ideas in particular are reflected in statements made by P. Nitze, one of the key authorities on military and political issues among the high-level advisers in the US Government. Says he: 'the criteria by which we will judge the feasibility of new technologies will be demanding. They must produce defensive systems that are reasonably survivable... New defensive systems must also be cost-effective at the margin, that is, it must be cheaper to add additional defensive capability than it is for the other side to add the offensive capability necessary to overcome the defense' [7.6].

And whereas the earlier statements of the SDI proponents held that the deployment of antimissile weapons would automatically result in curtailing offensive nuclear weapons, the later publications are not so optimistic. They note, specifically, that a BMD could only be effective if significant constraints were imposed on the number and characteristics of offensive systems and potential countermeasures. What is more, some of the Western experts have now come up with some specific suggestions as to such constraints, for example:

— limit the deployment in low orbits of means threatening the space-based components of ballistic-missile defenses;
— ban the development of new ballistic missiles with a shorter boost phase.

Judging by some Western reports these considerations had played a major role in US putting forward a ban on mobile ICBM's at the Geneva talks on nuclear and space weapons. According to some estimates the deployment of such systems, which feature a higher survivability of the ground-based component of the strategic forces in case of a nuclear strike, can be regarded as one of the many countermeasures to the space-based ballistic-missile-defense system.

It is paradoxical enough, but also remarkable, that hard-line proponents of unilateral decisions in military and technological spheres, who reject any mutually acceptable political arrangements aimed at strengthening security and arms limitations, are forced by the inexorable logic of the current strategic balance to appeal to political and legal arguments to protect their concepts.

The above considerations engender serious doubts concerning the feasibility not only of an 'absolute' BMD 'eliminating the threat posed by strategic nuclear missiles,' but also of the various limited versions of a BMD (area and point defenses), which, according to some SDI advocates, make the nuclear deterrence policy more reliable.

The critique of the SDI concept from the viewpoint of its implications for the strategic equilibrium includes, apart from those considered above, a number of other substantial arguments put forward both by Soviet and Western scientists

and military planners . It should also be emphasized that the many forms of a space-based BMD that do not claim to be 'absolute' can be thought of by both sides as a defense against a weakened retaliatory nuclear strike.

Each side, which in its assessment of possible military conflicts proceeds from the 'worst-case' analysis, will view the opponent's BMD as a threat to its retaliatory capabilities. And to thwart this threat this side will develop its countermeasures and develop its offensive forces. It will be recalled that both MIRV's and decoys made their appearance precisely as countermeasures to the other-side's potential ABM systems.

The higher antiretaliatory capabilities of a BMD give its possessor a strong incentive to launch a first strike.

These arguments, which became apparent back in the 1960s, were some of the direct reasons for signing the ABM Treaty of 1972, which was then considered to be a requisite instrument in the set of treaties to ban nuclear arms.

These considerations are sufficiently serious so that one could regard the SDI program as a manifestation of the desire to establish military superiority, to acquire first-strike capabilities with impunity, and to do away with any bans on offensive strategic forces. These apprehensions appear to be even more justified in the context of the steadily worsening political international climate of the last decades and of the well-established, inflexible (and hence dated) views of the many SDI advocates.

But even if one forgets about the political realities of today's world, believes unreservedly in the peaceful rhetoric of the SDI advocates and sets out to deploy a parallel BMD, even then a number of serious consequences lowering the stability of the strategic situation would follow.

As noted above, the immense destructive power of the nuclear arms levels off, to a certain degree, the differences in the characteristics of the elements of both-sides' offensive strategic forces. This allows a measure of destabilization in the political and military climate while peace is still preserved, an example of which is the current chill in US–Soviet relations.

The strategic equilibrium will be upset by the addition of space-based weapons. The efficiency of antimissile systems is, to a significant degree, dependent both on their technical performance (the accuracy of sensors, detection and targeting systems, the reliability of computer complexes of battle-management systems, the brightness of space- or ground-based lasers, etc.), and on the geographical arrangement of the offensive strategic forces of both sides. In addition, it will be difficult to verify many characteristics of the hypothetical defensive weapons not only by national technical means, but also by on-site inspection.

The hypothetical treaties, which some SDI proponents think will ensure that the space-based ballistic-missile weapons will be deployed step-by-step and that during this deployment the strategic balance will be maintained, would have to include a much wider range of issues than treaties limiting and curtailing the

offensive strategic forces. A historical analysis of US–Soviet arms-control talks tells us that a solution of these questions is highly unlikely, both politically and technologically.

The promises to share BMD technologies given in Washington aimed at providing gradual process in the simultaneous deployment of BMD systems by both sides and at maintaining the needed stability cannot of course be taken seriously because of these technologies being exceedingly sensitive both for antimissile system and for other key sectors of military technology, including first-strike and countermeasure antimissile capabilities.

These considerations again show that one side is sure to lag behind in the process of antimissile system deployment, which poses a serious threat to the stability of the strategic balance.

Should one side deploy, if only partially, a defense system against weakened retaliatory capability of the other side, the other side can regard this as a violation of conditions of mutual nuclear deterrence. And the other side can express its concern in a number of ways, from active and passive countermeasures to placing its reliance on the automatic 'launch on warning' strategy.

A BMD will of course be more effective when used against a weakened retaliatory strike than against a massive first strike, which is especially dangerous because in a crisis this will tip the balance of the strategic equilibrium. In a critical situation between two possessors of ballistic-missile defenses, each side will be better off by striking first. Moreover, a BMD will contribute to strategic instability because the so-called 'defensive' space weapons can be used as offensive weapons, which for a start could knock out a counterpart BMD on the other side (having spent only an insignificant part of its resources) .

It should be noted that the instabilities of a transitional period and the special instability of the strategic balance in a crisis are characteristic even for an idealized situation, ignoring the real problems to be encountered by the developers of ballistic-missile systems and measures against them, including the offensive weapons.

Studies have shown that space-based ballistic-missile defense itself is so unbalanced, that it would be safe to say that, should it be deployed, the macrosystem of the strategic balance would have no stability reserve at all.

7.3 Limited BMD's and the strategic balance

Following the early discussions in 1983, the emphasis now seems to have shifted from plans and feasibility of the nation-wide ballistic-missile defense designed to cover the entire US and the territories of its allies to the ideas associated with the feasibility of limited BMD's, namely area and point defenses.

One cannot ignore the staggering costs and complications, as well as the potential responses of the other side, which make President Reagan's 'Star Wars' program unrealistic.

A number of studies undertaken by both Soviet and American scientists support the conclusion made by Soviet Academicians in their Appeal to All Scientists of the World in April of 1983. They stated that antimissile weapons can give practically nothing to a country becoming a target of a sudden massive nuclear attack, since they are unable to protect the overwhelming majority of the country's population. It was noted with good reason that, taking into account the countermeasures installed by the other side, such a system would also be unable to prevent a retaliatory attack.

These obvious inferences fall on the deaf ear of SDI officials, who are currently engaged in developments that would eventually make the course of events irreversible. They put forward various arguments in favor of partial forms of a BMD that do not even claim to be effective.

They declare that even a BMD of limited capabilities, functions and scale that could be created before the year 2000 would have its 'stabilizing effect' on the political and strategic climate in the world. As for the global BMD, it would be with us all right, although a matter of long-term planning. Limited forms of the defense system are still considered by many members of powerful groups in the US Government to be an interim stage. Remarkably enough, there is no mention now of any constraints on using nuclear weapons in the hypothetical antimissile systems, even in limited ones. The Official Document of the US State Department of June 4, 1985 reads: 'We will continue to explore the promising concepts* which use nuclear energy to power devices which could destroy ballistic missiles at great distances' . Influential US experts, apart from the nuclear-bomb pumped X-ray laser, are actively discussing the need to use nuclear arms for antimissiles of the planned BMD against the other side's ICBM's in the terminal phase of their trajectories .

The intermediate, less-than-perfect ballistic-missile defenses are being justified, among other things, by the need to protect the US territory from 'third countries,' i.e., nations that might acquire nuclear arms in the near future and that could, as is believed by some Western experts, blackmail with their nuclear weapons even the great powers. It is also maintained that a limited BMD, although unable to handle a massive nuclear attack—neither a first nor a second strike—on city targets and industrial areas, would nevertheless be able to shield the country from accidental, unauthorized ICBM launches.

A limited BMD, it is maintained, would be a factor of deterrence simply owing to the heightened uncertainties in the strategic planning of the sides.

Some high-ranking spokesmen of the US Administration consider that it would be desirable and feasible to deploy in the foreseeable future a number of antimissible complexes (above all, ground- and air-based) for the point defense of ICBM launch sites, which become ever more vulnerable to the ever more accurate and powerful warheads.

These arguments do not hold water. Following the normal logic of politics and strategy, one can see that a more effective way to protect nations from nuclear blackmail, and even more so from the use of nuclear weapons, would be to strengthen the non-proliferation regime, to ease international tension overall and in those regions where there are near-nuclear states. Of course, in doing so the US and other nuclear powers would have, following the Soviet lead, to demonstrate in practice to other nations their willingness to limit and cut their respective nuclear arsenals, in full accordance with Article VI of the Non-Proliferation Treaty.

Other useful measures would be some steps in the direction of reducing the probability of a nuclear war in the spirit of the bilateral Agreement on the Prevention of Nuclear War signed in 1973 [7.11].

During the Geneva summit, an agreement was reached for experts to study the question of founding US–Soviet nuclear risk reduction centers

. In this connection the following would seem pertinent. In a special study performed by the US Strategic Air Command (on order from Senators Nunn and Warner, who are currently looking into the issue of joint centers aimed at reducing the threat of an accidental nuclear war), nine potential means of delivery of nuclear weapons by 'third countries' are listed (including terrorist groups) . Analysis of these means against the background of any, even ideal capabilities of future antimissile weapons suggests that none of them could be intercepted or neutralized by a BMD, wherever the component is based—in space, in the air, or on the ground.

As regards the uses of a BMD to protect against accidental, unauthorized launches of nuclear-armed missiles, this may appeal to some superficial observers. But those advocating this idea make a point of overlooking the fact that, on the technological side, such launches might be countered by some simpler means, which would also be not so destabilizing from military and political standpoints, for example, by improving the reliability of the self-destroying devices in strategic delivery vehicles with on-board guidance systems, which would enable the vehicle (but not the nuclear warhead) to be exploded on command from the control center with minimal damage to the population and environment.

It is also necessary to weigh the risks of an accidental launch, not only in terms of military, political and economic costs of the deployment of a BMD, but also in terms of the hazards of the BMD self-activizing as a result of an error in the detection and identification system or in the battle-management system of the ballistic-missile defense, a subject covered in more detail in Chapter 5. It was estimated that the probability of an error or a failure in the battle-management system would be much higher than the probability of a random launch, especially if the nuclear arsenals of both sides were cut drastically in accordance with equitable agreements (provided, of course, that the ratio of the number of

warheads of one side to the number of units in the strategic forces of the other side be the same), and if the reliability of the early-warning and control systems were to be steadily improved.

Also contrary to the dialectics of the interplay of strategic forces as a complicated macrosystem is the notion fostered by some representatives of the Reagan Administration that a limited BMD will 'introduce greater stability into the strategic calculus on both sides,' owing to the mounting uncertainties of the first-strike outcome.

First, the advocates of this thesis make a point of deliberately ignoring the unilateral obligation of the USSR not to use nuclear weapons first, which by the way dictates even more severe control measures to prevent an accidental launch of a nuclear missile. If the US and its allies followed suit, the world would become more stable and secure, a world with a lower probability both of a planned first strike and of accidental missile launches.

Second, the present-day strategic situation has inherent in it a sizeable measure of uncertainty determined by a multitude of different factors. Such an uncertainty, within certain limits of course, could play a stabilizing role. Lower uncertainties, for example in respect to a devastating first strike, would play an apparent destabilizing role. On the other hand, the escalation of uncertainties above some level that has been established in recent years seems to be quite dangerous as well. This additional uncertainty, taken into account by the strategic planners of one side, is bound to affect the uncertainties in the planning by the other side, which in turn would lower the stability of the current strategic balance and increase the threat of a nuclear war.

According to many knowledgeable experts, the uncertainties in the planning of a devastating first strike are still too high under modern conditions. To be sure, in the longer run the probability of such an attack could increase due to initiated by the USA further buildup of warheads, improvements of their accuracy and higher yield*, and also as a result of the deployment of novel means of strategic antisubmarine warfare. But this goes to prove that there is an urgent necessity to take definite measures to overcome the situation in which a first strike becomes ever more attractive.

Nuclear weapons freeze, both quantitative and qualitative, would be a really effective measure aimed at preventing the buildup of first-strike capability. This is to be regarded as the first step in the direction of nuclear arms reduction aimed at their complete elimination by the year 2000. Another important step would be the total ban and cessation of all nuclear explosions. Specifically, such actions of the sides would reduce the number of high-accuracy nuclear weapons in their arsenals, i.e., weapons that could destroy hard targets and command centers. It is also necessary to undertake agreed actions to limit antisubmarine operations, which also undermine the strategic stability. There are also a number

of other measures that could reduce the probability of a devastating first strike. Suggestions to this effect are being put forward persistently by the USSR. These suggestions take into account the security interests of both sides and the constructive ideas proposed in the West.

Last, a BMD system designed to protect ICBM launch sites in the US beyond the limits stipulated by the ABM Treaty of 1972 and the Protocol thereto of 1974, as a key element of the US military doctrines of 'protracted' and 'limited' nuclear wars, would have a destabilizing effect as well.

The Washington strategists are toying with the idea of 'limited' or 'controlled' exchange of nuclear strikes against ICBM fields without damaging industrial and administrative centers, without enormous casualties among civilian populations, these exchanges terminating the hostilities on the conditions favorable to the United States. The Soviet military doctrine, which is based on realistic views of the nature of nuclear war, rejects the idea of its 'limitedness' as unsound and unrealistic, and hence exceedingly dangerous.

Nonetheless the USSR and its allies are forced to take into account these concepts of US political and strategic thinking, however unrealistic they may be.

In the pre-nuclear era, if a nation followed unrealistic warfare schemes, this in the first place meant that the probability of that nation being defeated in the war increased. In a way, from a purely military point of view, this played into the hands of the nation's potential opponents. But nowadays one has to approach this differently. Leadership that is guided by doctrines and concepts that fail to reflect the real nature of war and the systems character of the strategic balance, leadership that believes in the possibility of 'controlled' and 'limited' warfare using weapons of mass destruction, is heading for a war with an unpredictable course of events, which would be bound to force it to use such means that would eventually lead to a world catastrophe.

7.4 BMD and European security

The military and political implications of the deployment of a space-based antimissile system as discussed in this book would, for the most part, affect the situation in Europe, as one of the most important regions of the world.

US Government spokesmen try to persuade the West European NATO members that by installing their antimissile 'shield' the US would be able to protect not only itself but also its allies. It is often stressed in US official documents that the US continues to honor its commitments to President Reagan's program whose goal is to create an 'absolutely leak-proof defense' for the US and its allies. Moreover, as noted by the head of the Strategic Defense Initiative Organization Gen. J. Abrahamson the US 'concept of an effective defense is one which protects our (American—*Eds.*) allies as well as the United States'

Is it possible in principle to provide for such a 'leak-proof' defense for the allies using the American antimissile 'umbrella'?

The very concept of the proposed space-based ballistic-missile defense is based on the assumption that each layer and component of the defense is less than perfect, and so even theoretically it cannot ensure reliable defense. Each defensive layer is called upon to stop the 'leakage' through the previous layer, i.e., to destroy the remaining warheads.

Bringing American allies under the BMD 'umbrella' would imply protecting them from nuclear vehicles other than ICBM's. Characteristic of the European theater are medium-range ballistic missiles with depressed trajectories, shorter flight times, and so on.

These and other factors strongly suggest that it would be impossible to apply all the layers of the proposed space-based ballistic-missile-defense system to protect Europe.

The reports published by the study teams sponsored by the US Administration (headed by Fletcher, Hoffman, and others) referred to the possibility of the advent of fast-burn boosters (with boost phase 80 s or so) as a serious countermeasure. But unlike ICBM's, medium-range missiles, and even more so theater missiles, have boost phases much shorter than the above lower limit required for a boost-phase interception layer to engage them.

Subsequent layers would also function within unrealistic time limits, since the total flight time of MRBM's is two or three times shorter than that of ICBM's. The task of the subsequent layers would also be made more difficult because the attack could not be weakened markedly by the previous BMD layers.

Since MRBM's fly at a lower altitude than ICBM's in their midcourse phase, this excludes or at least limits the uses in the European theater of many laser types due to substantial atmospheric absorption of laser beams. Using lasers whose beams penetrate the atmosphere would be hindered by the typically overcast skies over Europe. In addition, low flight altitudes would require more space-based BMD components to be constantly on station there, since the ranges of the weapons would be shorter.

Additional demand would be imposed on kinetic-energy weapons. As noted earlier in the book, the altitude of an orbit of a space-based battle station is selected depending on the total number of carriers and its active service life in orbit. The lower trajectories of MRBM's and their shorter exoatmospheric flight times would call for either longer ranges of the antimissile projectiles (and hence more sophisticated designs) or lower orbits for the stations with all the implied consequences, the most crippling one being the need to shorten the in-orbit life of the station.

In short, the proposed American BMD would be even less effective for overpopulated Europe (which would suffer badly in any case) than for the US itself.

It is also worth noting that destroying from space many nuclear weapon delivery means deployed in the European theater seems infeasible in general. This

applies to bombers, cruise missiles (ground-, air-, and sea-based), 'nuclear artillery' and some other vehicles, which together account for thousands of units of nuclear weapons, including theater weapons.

The evolution of the tasks of the SDI program (its initial goal was to protect the territory and population of the US) has led to a renewal of interest in area and point ballistic-missile-defense complexes for Europe as well.* Emphasis on these ABM defense complexes would imply the predominant development of what is called the terminal interception layer of a BMD. There is a significant measure of similarity between the technical means of an area and a point ABM defense system and the terminal interception layer of a comprehensive space-based ballistic-missile defense.

It is often held that for Europe the best form of antimissile system is a limited BMD, since the terminal velocity of warheads of MRBM's and other similar vehicles is much lower than that of ICBM's. However, one should not overlook the fact that as a result of other characteristics of their trajectories the flight-time from the beginning of the selection of decoys to the target is practically the same due to atmospheric effects.

As with a comprehensive space-based BMD, local BMD could be thwarted by a set of relatively cheap countermeasures, which might, for example, easily deceive the sensors of battle-management systems.

Should relatively efficient point BMD be deployed to protect, say, ballistic-missile silos primarily against MRBM's, one possible countermeasure could be to saturate the defense with targets.

The concept of limited (area or point) defense is, as a rule, associated with the defense of an area on which some important strategic installation is located. Selection of an area should be guided by some criteria. But in Europe, because of its dense population and concentration of industry, it would be hardly possible to single out certain regions of special importance. Aslo, there are no ICBM fields here whose protection would warrant a BMD complex.

Admittedly, for a certain offense-to-defense ratio local BMD complexes could reduce local devastation, but overall this does not contradict the thesis that for Europe a comprehensive space-based antimissile system would be ineffective in a full-scale nuclear conflict.

But there is more to it than this. According to the ABM Treaty of 1972, the US undertook 'not to transfer to other States and not to deploy outside its national territory ABM systems or their components' (Article IX). It follows thus that any joint activities of the US and its allies to implement the SDI plans would eventually be a direct violation of the Treaty. The same is true of the point ABM defense, which is claimed officially to be an MRBM defense, although it can also be used as an ICBM defense, which is a violation of Article VI of the ABM Treaty.

This, however, does not stop certain groups in the US and in some of its allied countries from joining forces in developing a space-based antimissile system.

* For more details see Chapter 3.—*Eds*

Now the SDI program supporters appeal for stronger integration of the US and its West European allies in the political, military and economic spheres. The US Administration is looking forward to gaining from such cooperation by augmenting its technological, economic and manpower resources even without actually bringing them in from other countries, with overseas research and development organizations simply carrying out American contracts.

Representatives of the US Administration explore every avenue to draw into the SDI program governmental and private organizations in West Europe. Some countries have already agreed to participate in SDI efforts. The SDI officials are confident that many European firms, whatever the official stand of their respective governments, will be unwilling to lose major contracts and will join the SDI program. One of the incentives for such firms may be fears of not gaining access to American technologies in the course of the SDI work. These fears, by the way, also predetermine the nature of discussions in the governmental, industrial and academic circles of some European countries. On their part, the Administration spokesmen in their attempts to lure European private firms lavish promises upon these firms of billion dollar contracts concerning the SDI.

The wide involvement of West European business in the implementing of the US plans for militarizing space is pregnant with hazards of destabilizing the international situation. If involved in the 'Star Wars' program, West European firms in the various sectors of business would, for one thing, give a mighty impetus to the work, and for the other, would become a powerful SDI lobby in West Europe. In consequence, involving West European private business, the US Administration would be able to make European countries more dependent on US policy—another contribution to international tensions.

Much in the position of West European allies of the US stems from their false views and false ambitions. For example, the desire of the FRG to get a finger in the SDI pie is explained, if only partially, by the fact that, being a NATO member and a possessor of significant economic potential, this nation has no nuclear weapons, and so, according to some of its leaders, it cannot play a fitting role in world policy. The FRG leadership is thus looking forward, through the country's participation in the 'Star Wars' program, to gaining indirect access to nuclear arms. Some high-ranking politicians in that country state that only by participating in the SDI could the FRG and other European countries increase their influence in the international community.

But these illusions are dangerous and senseless—the international prestige of any country has nothing to do with its military might. Also illusionary are the hopes of acquiring some defensive superweapons. West Europeans will only be 'entrusted' with secondary and, obviously, isolated projects. The US is not interested in strengthening its allies in such an important sphere, and will never reconcile itself to the possibility of undermining its own security through possible leakages of sensitive military information abroad.

Introduction of a new element into the nuclear calculus in Europe, just as in the world at large, will appreciably complicate and entangle the assessments of the actual capabilities of the sides, will hinder the search for objective criteria of parity and the observation of the principle of equality and equal security. One cannot help agreeing with those Western researchers who note that a BMD will 'leave Europe as vulnerable as before' [7.15].

The attitude of West European countries to the SDI program becomes a touchstone in inter-European relations. So, already now we witness one of the most serious complications of the last decades in France-FRG relations caused by the differences in the two countries' attitudes to the SDI. Whereas the FRG endeavours to get from the US a separate package of projects within the SDI framework, France suggests the West European *Eureka* project, which is counterposed to the American project and is meant as a way to cement West Europe by stimulating the development of science and technology on the continent. The results of the R&D projects could be used for military purposes as well. This could not but influence the political climate of Europe as a whole.

The attempts to involve West European countries in the SDI cause well-founded concerns in realistically thinking Europeans about the fate of the ABM Treaty of 1972 and about the future of détente on the continent. Security cannot be strengthened by one side's attempts to create a superior system of arms (even if called defensive). The inclusion of the Europeans would only increase the number of people having delusions concerning the true purposes and real possibilities of the SDI, would result in a great deal of time and resources wasted, would undermine the West European economy and would raise the level of risks on the European continent.

Some of the American proponents of the Strategic Defense Initiative believe that if both the US and the USSR had BMD's, this would do away with some of the problems of the strategic balance between East and West owing to the devaluation of the French and British nuclear forces. But this is a mistake. At least because one could hardly expect that France and the UK would remain passive observers if confronted with such a course of affairs. It is quite obvious that the many countermeasures, including the modernization and buildup of offensive nuclear weapons and some active countermeasures, would be available in each of the two nations, let alone in a wider West European union.

Overall, many things suggest that the arguments of the American (or NATO) 'shield' to protect West Europe are attractive for some Europeans. The above analysis leads one to conclude that the real goal of US strategists is to use the 'shield' in a crisis to protect the United States from a retaliatory strike, and to use Europe as an arena in which the battle might be fought out. This conclusion is supported by the fact that the US did not undertake not to use nuclear weapons first, which for Europe, with its strategic geopolitical position, is an especially ominous sign.

The national leaders of those West European countries which plan to contribute in some form or another to the SDI effort try to persuade the public opinion of their countries by arguing that they are only planning to participate in the R&D work, and as for the actual deployment of a BMD system, this is going to be the subject of separate talks with the US. But by the time of those talks, the West Europeans will be head over ears in SDI projects, which, as noted above, will produce a powerful lobby including military industrialists and related politicians that will push through the deployment of space-based ballistic-missile-defense system.

What is more, the talks between the US and its allies can simply be used as a cover, as was really the case before the deployment of the American medium-range missiles in Europe, when the so-called 'double-track' decision was taken.

In fundamental matters, when handling the issue of the expediency of antimissile systems, the United States often just 'forgot' the interests of its allies. For the West European political leaders, the official statements of the US Administration about its plans with respect to the deployment of a BMD, for the most part, came quite unexpectedly. Recall the beginning of 1967, when the President of the United States promulgated his plans to deploy ABM defense systems and submitted to the US Congress a request to allocate the required $375 million. The Administration behaved similarly in 1969, when it decided to revise in principle the structure of the planned ABM defense system and switch from its planned 'thin' defense based on the Sentinel missiles to an ABM defense based on launch sites for the Safeguard missiles. Also out of the blue for the allies came President Reagan's March 23, 1983, speech, which gave a fresh impetus to the development of a comprehensive ballistic-missile defense.

There are no grounds for believing that when dealing with further stages of the development of the SDI plans the US leadership will provide more information to its allies and consult with them about its plans. There will, of course, be exceptions, in situations like the present one, when the US itself needs support for its program (in a wide variety of forms) from its allies. This warrants the inference that in addition to the allies' resources, another interest the US seeks in Europe is to enlist political support for the SDI program.

According to official documents of the US Department of Defense, both sides will acquire their space-based BMD's in a more favorable international climate than currently exists. It is stated that 'a deployment of defensive systems would most usefully occur in the context of a cooperative, equitable, and verifiable arms control environment that regulates the offensive and defensive developments and deployments of the United States and Soviet Union' . If the American side really thinks so, it would perhaps be more logical to expedite now the development of agreements to this effect, all the more so since even from the viewpoint of SDI proponents the program would be hard to realize otherwise. Clearly, the USSR will never sign a treaty with the USA, that does not meet the

conditions of equality and equal security. These arrangements would be better safeguards of peace, for Europe too, than those that, in the opinion of the US, could provide for any form of BMD. It would also be of importance that this approach would prevent a senseless waste of enormous funds and brainpower.

The inclusion of West European countries into the US 'Star Wars' program may be seen as a victory of adventurism in West European policy, it would imply a new round of arms race destabilizing the strategic balance, instead of reducing arms in Europe.

Real security on the European continent cannot be achieved through the militarization of space or the deployment of new weapons on the ground. A major landmark on the path to a stable Europe could be the realization of the proposals made by General Secretary M.S.Gorbachev in his Statement of January 15,1986, to ban completely the Soviet and American medium-range missiles in Europe, both ballistic and cruise. To this end, the USA would have to undertake not to supply American-made strategic and medium-range missiles to other countries, and the UK and France not to build up their respective nuclear arsenals. The USSR would do the same. The realization of the further stages of the plan as proposed by the USSR would completely free Europe of nuclear arms.

7.5 Conclusion

To sum up: should the US go on with its plans of developing and deploying one or another of the versions of the proposed space-based ballistic-missile defense, this would erode the macrosystem of the strategic balance. A combination of antimissile weapons, developed and deployed beyond what is allowed by the ABM Treaty of 1972, with offensive nuclear weapons makes the strategic equilibrium less stable than without the BMD. Even if the USSR installs its countermeasures to restore strategic parity, the military and political balance will in reality be less stable, if one takes into account those factors of instability which are inherent in the comprehensive space-based ballistic-missile-defense system.

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Chapter 8

Legal aspects

Earlier in the book we concerned ourselves with the many technological, military and political aspects of the proposed 'Star Wars' program. In some chapters (e.g., in Chapter 1) legal aspects were touched upon, which is quite natural because at times it is difficult to draw a demarcation line between various aspects. This chapter concentrates on the legal issues and assessments, for which purpose some legal background information would be in order.

8.1 Background

Beginning in the 1970s and early 1980s, some draft treaties on the nonuse of force, of both a universal and regional nature, included, among other obligations, proposals to ban specifically the use of force in space. So, Article 1 of the Soviet draft World Treaty on the Non-Use of Force in International Relations, which has been under consideration by the United Nations since 1976, proposes that nations should refrain 'from the use of armed forces involving any types of weapons, including nuclear and other types of weapons of mass destruction on land, on the sea, in the air or *in outer space* (italics ours—*Eds.*), and also not to threaten such use' [illegible].

The 1983 Political Declaration of the Warsaw Treaty Member States on the conclusion of a treaty on the mutual renunciation of the use of military force and the maintenance of peaceful relations between the Warsaw Treaty member states and the members of the North Atlantic Treaty states that 'the core of the Treaty could be the mutual commitment of the States members of the two alliances not to be the first to use nuclear or conventional arms against one another, and thus not to be the first to use against one another military force in general' [illegible]. The Declaration notes that this commitment would also extend to cover spacecraft. An essential part of the treaty could be an undertaking not to endanger the security of international sea, air and *space* (italics ours—*Eds.*) communications passing through areas in which no state has jurisdiction. These proposals received confirmation and further development in the Communique of the

Member States of the Warsaw Treaty of May 7, 1984 [illegible] and the Declaration of the CMEA Member States entitled 'Maintenance of Peace and International Economic Co-Operation' of June 14, 1984 [illegible].

The most detailed and comprehensive among the space-related draft treaties submitted so far was the draft Treaty on the Prohibition of the Use of Force in Outer Space and from Outer Space Against the Earth proposed by the USSR in the United Nations in 1983 [illegible]. The draft elaborates on the principle of nonuse of force in and from space in terms of both political and legal obligations of states and in terms of practical measures. It expressly bans the development, testing, and deployment of space-based weapons.

As for the political and legal obligations, they are set forth in Article 1 of the draft, which prohibits the use or threat of force in outer space and the atmosphere and on the ground through the utilization, as instruments of destruction, of space objects in orbits around the earth, on celestial bodies or stationed in space by other means. It is further prohibited to resort to the use or threat of force against peaceful space objects in orbits around the earth, on celestial bodies or stationed in space by other means.

A certain analogy with the Soviet proposal referred to above can be found, with application to the moon and other celestial bodies, in the 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies. Article 3 of this Agreement states: 'Any threat or use of force or any other hostile act or threat of hostile act on the moon is prohibited. It is likewise prohibited to use the moon in order to commit any such act or to engage in any such threat in relation to the earth, the moon, spacecraft, the personnel of spacecraft or man-made objects.' (Under Article 1 of the Agreement, all its provisions relating to the moon apply also to other celestial bodies within the solar system, other than the earth.) One should, however, take into consideration that, first, the Agreement has limited scope and, second, that only a small number of states, including neither the United States nor the Soviet Union, are at present signatories to it.

The proposal to ban forever the use of force in space and from space against the earth, as well as from the earth against objects in space was also included in the Soviet draft resolution on 'Use of Outer Space Exclusively for Peaceful Purposes for the Benefit of Mankind.' The draft was submitted by the Soviet Union at the 39th Session of the United Nations General Assembly in September 1984 [illegible].

It also contains other provisions of political and legal nature of fundamental significance for prohibiting the militarization of space and stopping the spread of the arms race to space. The draft proposes that the United Nations General Assembly should proclaim it the historic responsibility of all states to ensure that the exploration of space be carried out exclusively for peaceful purposes, for the benefit of mankind, and to declare in this connection that excluding space from the arms race should become a strict norm of state policy and a generally recognized international obligation.

Like the 1983 draft Treaty, the Soviet draft resolution submitted to the 1984 General Assembly proposed that political and legal principles prohibiting the militarization of space should be supplemented and reinforced with specific bans to guarantee that those principles be observed by all states. Unfortunately, some important points of the Soviet draft were not reflected in the resolution of the United Nations General Assembly passed on the basis of the Soviet draft and entitled 'The Prevention of the Arms Race in Space' (Res.39/59,12 Dec.1984). Note, however, that the resolution highlighted the duty of all states to refrain in their activities in space from the use or threat of force.

Let us now turn to those specific prohibitions and limitations of the military use of space that already exist in international law. These prohibitions and limitations either exclude specific areas of space from the sphere of military activities or prohibit and limit the uses of particular types of weapons and other means in space for military purposes.

The most far-reaching prohibitions extend to the moon and other celestial bodies, which, according to the Outer Space Treaty of 1967, should be used 'exclusively for peaceful purposes.' The illustrative list of types of activities prohibited on the moon and other celestial bodies, as provided in Article IV of the Treaty, includes the stationing of nuclear weapons or other kinds of weapons of mass destruction, the organization of military bases and fortifications, the testing of any type of weapon and the conduct of military exercises. The use of military personnel for scientific research or for any other peaceful purposes and the use of any equipment or facility necessary for peaceful exploration of the moon and other celestial bodies are permitted.

The illustrative list was supplemented and expanded in Article III of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies of 1979, which adds to the list of prohibited activities the placing in orbit around the moon or on other trajectories to or around the moon objects carrying weapons of mass destruction, or using such weapons on or in the moon.

The complete prohibition of military activities on the moon and other celestial bodies is sometimes referred to as demilitarization, which is actually a misnomer in this case. A more appropriate term is nonmilitarization.

As for space as a whole, including near space, i.e. the earth's environs, there is no complete prohibition of military activities here yet. Among specific measures limiting the military use of space, the most significant is the obligation of the parties to the Outer Space Treaty of 1967 'not to place in orbit around the earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction... or station such weapons in outer space in any other manner' (Paragraph 1, Article IV).

According to its broadest interpretation, the term 'weapons of mass destruction' covers such types of weapons as nuclear, chemical, and biological arms and other types of weapons comparable to the above ones in terms of their

destructive power or damaging effect, including those that may be developed in the future. The stationing of all kinds of such weapons in orbit around the earth or in space 'in any other manner' is prohibited. It is the opinion of many jurists that the concept of stationing 'in any other manner' covers the stationing of such weapons on spacecraft even if the latter do not complete a full revolution around the earth [8.7].

A number of important conditions limiting the possibilities of military activities in space have been included in bilateral and multilateral treaties and agreements providing for partial measures in the area of disarmament. Test explosions of nuclear weapons or any other nuclear explosions in space are outlawed by Article I of the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, in force since October 10, 1963. For this ban to be effective, it is important that it be observed by all nuclear powers, including the People's Republic of China and France, which have not yet adhered to the Treaty.

Any use of means affecting space or the earth's natural environment from space for military purposes are banned by the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, in force since October 5, 1978.

Certain quantitative and qualitative limitations on the military uses of space are also contained in bilateral agreements between the USA and the USSR.

The development, testing and deployment of space-based antiballistic-missile systems or components are prohibited by Article V of the Treaty on the Limitation of Anti-Ballistic-Missile Systems of 1972. By the Treaty and the Protocol thereto of July 3, 1974, the USA and the USSR undertook to have 'one ABM system deployment area' and 'no more than one hundred ABM interceptor missiles at launch sites.' The so-called 'broad interpretation' of the Treaty [illegible]. An analysis of the Treaty and all attempts at its arbitrary interpretations in the context of the Strategic Defense Initiative is given in Sec. 8.2.

In accordance with the Interim Agreement on Certain Measures with Respect to the Limitation of Strategic Offensive Arms (SALT I) signed in 1972, the USA and the USSR undertook to limit the number of ICBM launchers, a measure which also placed certain quantitative limitations upon the military uses of space. Further quantitative and qualitative limitations would be imposed by the SALT II Treaty signed by the USA and the USSR in 1979. According to the Treaty, the parties undertook not to develop, test or deploy 'systems for placing into Earth orbit nuclear weapons or any other kind of weapons of mass destruction, including fractional orbital missiles' [illegible]. This obligation would strengthen the ban on stationing weapons of mass destruction in space.

In addition to the prohibitions and limitations listed above, multilateral and bilateral international agreements include a number of provisions that could

be characterized as indirect limitations of military activities in space. An example is the requirement for consultations in the event that an activity or experiment planned by one state in space would cause harmful interference with the peaceful exploration and use of space by other states (Article IX of the 1967 Outer Space Treaty), the prohibition against interfering with the national technical means of the other party used for verifying compliance with the provisions of the SALT I Treaty and the Treaty on the Limitation of Anti-Ballistic-Missile Systems (Articles V and XII, respectively), and some others.

The above prohibitions and limitations in their entirety entitle us to think that a principle of international law concerning the use of outer space for peaceful purposes is gradually taking shape. For the time being, this principle appears essentially as a program, a guiding idea, a goal for the future, but its normative content is rather substantial even today (complete prohibition of military activities on the moon and other celestial bodies, serious limitations upon military activities in space in general). The principle of the use of outer space for peaceful purposes implies that states should strive actively and purposefully for the complete exclusion of space from the sphere of military activities, employing to this end both general and partial disarmament and arms limitation measures.

A number of recent Soviet proposals are aimed at achieving this end. If adopted, they would be a reliable barrier against the spread of the arms race to space.

The goals of these proposals are to exclude completely the use of force in space or from space against the earth, to eliminate the material basis for such a threat, and to guarantee that space objects would not represent a military threat to other states and would themselves enjoy security.

Specifically, these were the objects of the draft Treaty on the Prohibition of the Stationing of Weapons of Any Kind in Outer Space (1981) , the draft Treaty on the Prohibition of the Use of Force in Outer Space and from Outer Space Against the Earth (1983), the draft General Assembly Resolution on the Use of Outer Space Exclusively for Peaceful Purposes for the Benefit of Mankind (1984), the draft General Assembly Resolution on International Cooperation in Peaceful Development of Outer Space Under the Conditions of Its Nonmilitarization (1985) . The USSR was pursuing the same aims when it proposed to the US Government bilateral talks on the prevention of the militarization of space . To make the achievement of positive results in multilateral and bilateral negotiations easier, the USSR in August 1983 unilaterally proclaimed a moratorium on stationing in space any forms of antisatellite weapons , and in June 1984 proposed to the USA, on a reciprocal basis and starting on the opening date of the talks, a moratorium on the testing and deployment of space-based weapons, which could be joined by other states .

Striving to prevent the arms race in space and to put an end to it on the ground, the USSR suggested to initiate US–Soviet talks on space and nuclear

weapons, which opened in Geneva in March 1985. At these talks the Soviet side suggested that both sides ban offensive space-based weapons and cut nuclear arms capable of reaching the territories of the USA and the USSR radically, by 50 per cent . The Statement of General Secretary of the CPSU Central Committee M.S.Gorbachev of January 15,1986, outlined the Soviet program for the complete and universal elimination of nuclear weapons by 2000 with the USA and USSR jointly undertaking not to produce, test or deploy offensive space-based weapons .

As regards multilateral talks, the Soviet draft Treaty on the Prohibition of the Use of Force in Outer Space and from Outer Space Against the Earth submitted for consideration to the Conference on Disarmament by a decision of the General Assembly, provides for measures that, first, preclude the uses of space objects as instruments of destruction or carriers of weapons and, second, guarantee the safety of the space objects themselves.

The first of the above groups of measures is provided for in paragraphs 1, 2, and, partly, 5 of Article 2 of the draft Treaty. They prohibit testing and stationing in orbit around the earth, on celestial bodies or in any other manner any weapons designed to destroy objects on the earth, in the atmosphere or in space (Paragraph 1, Article 2). It is also prohibited to utilize space objects in orbit around the earth, on celestial bodies or stationed in space in any other manner as means to destroy any targets on the ground, in the atmosphere or in space (Paragraph 2, Article 2).

The second group of measures to prevent the use of force against space objects themselves is provided for in paragraphs 3, 4 and, partly, 5 of Article 2. They include a ban on destroying, damaging, or disturbing the normal functioning, or changing the flight trajectories of space objects of other states (Paragraph 3, Article 2), and makes it incumbent upon States Parties not to test or create new antisatellite systems and to destroy any antisatellite systems that they may already have (Paragraph 4, Article 2). Paragraph 5 of the same Article specifically prohibits testing or using manned spacecraft for antisatellite purposes.

Articles 4 and 5 of the Soviet draft provide for the verification of compliance with the Treaty's obligations and for the settlement of possible disputes concerning its implementation. To this end, it is envisaged that each State Party shall use national technical means of verification in accordance with international law (space tracking means and other means available to the Parties on land, at sea, and in space), each Party shall undertake not to interfere with the national technical means of verification of other States Parties and shall exchange information and consult with one another. The draft also provides for using other international procedures, including the establishment of a Consultative Committee of States Parties to the Treaty, to be convened at the request of any State Party.

The above Soviet proposals, if adopted, would ensure that the arms race not to be extended to space, would encourage further progress in arms control in general, would promote international cooperation in the development and uses of space for the benefit of all nations.

8.2 SDI and international law

The US Administration is now trying to give to the Strategic Defense Initiative the appearances of legality, it does not stint assurances that the SDI concept is in full accordance with all the international obligations of the USA. Such assurances pour out from the Pentagon, the State Department and from the President himself. During his talk with Soviet journalists President Reagan said that the USA would never violate the US–Soviet ABM Treaty [illegible]. Let us take a look at the relationship between the international obligations of the USA and the goals and implementation of the SDI.

Since it entered into force in 1972, the ABM Treaty has been universally regarded as a cornerstone of the entire system of international arms-control agreements. This Treaty of unlimited duration is important because of the organic interrelation between strategic offensive and defensive weapons. So, the preamble to the Treaty says: 'Effective measures to limit anti-ballistic-missile systems would be a substantial factor in curbing the race in strategic offensive arms and would lead to a decrease in the risk of outbreak of war involving nuclear weapons.'

As follows from the Treaty's title, preamble and main provisions, its main goal is to discourage maximally both sides from creating ballistic-missile defenses. The primarily obligation pursuant to the Treaty is 'not to deploy ABM systems for a defense of the territory of its country and not to provide a base for such a defense' (Paragraph 2, Article I).

The officially proclaimed principal idea of the SDI, its final goal, is the creation of a comprehensive ballistic-missile-defense system with space-based components, i.e., a goal directly opposite to the goal of the ABM Treaty and the obligation pursuant to the Treaty as quoted above. In President Reagan's March 23, 1983, speech, the ultimate goal of the SDI was defined as 'eliminating the threat posed by strategic nuclear missiles.' That is to say, in the final analysis, an 'antimissile shield' to cover the entire USA is proposed, which is prohibited by Article I of the Treaty.

The constant tenor of official statements of the US Administration spokesmen concerning the SDI is that the proposed program is simply scientific in nature and that a decision as to the expediency of the deployment of a BMD will be made no sooner than the beginning of the 1990s. It is stated, therefore, that as of now the SDI program does not violate the ABM Treaty. But what is now represented as innocent 'investigations' is in fact a program unparalleled in terms of scale, costs and concentration, which is aimed at creating a new class of weapons, namely offensive space-based weapons. At the same time, this is a program of step-by-step creation of what in the Treaty is called the 'base' of the ABM defense of the territory of the country. The ingredients, building blocks, of this base will be numerous technologies, devices, componentes, models, and mock-ups, which are or will be developed and tested in the foreseeable future according to the SDI program.

In addition to the general ban on ABM defense of the country's territory and on the development of a base for such a defense, the Treaty and the Protocol of July 3, 1974, establish specific quantitative, qualitative and geographical limitations on the ABM defense. So, the Parties to the Treaty agreed to have only one ABM system deployment area with a preset number of launchers, ABM interceptor missiles at launch sites, and so on.

Exceedingly important among these specific limitations is the obligation 'not to develop, test, or deploy ABM systems or components which are sea-based, space-based, or mobile land-based' (Article V). In apparent violation of this obligation, the SDI is oriented at the creation of a full-scale space-based ballistic-missile-defense system.

The US Administration is now using some legal tricks in efforts to find loopholes in the clear and unequivocal ban on the development of systems and components of such BMD systems. So, it is trying to prove that Article V does not prohibit work on the SDI program, first, because the program is allegedly confined to preliminary stages of the development of elements of such a system and, second, because the elements themselves allegedly do not fall into the category of 'components' listed in Article II of the Treaty.

A thorough legal scrutiny of the Treaty reveals the groundlessness of these attempts. Article V bans not just some final stages of the development of space-based antimissile-defense components, but bans them *in general altogether*. If, however, one turns to the SDI program for the next years—even in the form in which it is officially presented in the reports of the Pentagon to the US Congress—one can see that it provides not only for research, as is maintained by some official US spokesmen, but also for the development and tests of the elements of a future BMD system. So, in the Pentagon report of 1985, tests to determine the effectiveness of the technologies developed and demonstrations with models, and so on, are mentioned. Some of these tests and 'demonstrations' are planned already for 1987.

Accordingly, this is a violation of the ban not only on the development of the system and its space-based components, but also on their tests. Juggling with words, using the term 'demonstration' instead of 'tests,' does not change the gist of the matter. A group of prominent US experts who studied the question presented their opinions in a report to the organization known as the National Campaign to Save the ABM Treaty in which they noted: ' "Demonstration" is a term the Pentagon often uses in describing activitites the ABM Treaty language terms "tests." '[illegible].

The same purpose is served by the use in official documents of the US Administration of the notions 'subcomponents,' 'devices,' etc., instead of 'components' of the system, whose development and tests are prohibited by the Treaty. In the opinion of the above-mentioned experts, the narrow understanding of the term 'components' ignores the history of the Treaty talks and is based on the

exceedingly limited concept of the nature of the components constituting an ABM system.

But there are other important things. It is obvious that, from the very beginning, the SDI program was in essense oriented at seeking ways and means of producing a system that is banned by the ABM Treaty. The program as a whole, not just its final stages, violates the Treaty. Progressing from stage to stage, it will come ever more expressly to contradict the very letter of the Treaty with specific bans pursuant to it.

Before the Geneva summit some of the high-level advisers to the US Government tried to make the Administration adopt the so-called more 'liberal' interpretation of the Treaty.

The 'new interpretation' of the Treaty and the history of its conclusion undertaken at the Pentagon has led to the belief that the development and tests of an ABM system based on 'new physical principles,' and perhaps even the deployment of such systems, are not banned by the Treaty. R.McFarlane, a former national security adviser, stated that the development and testing of such systems are allowed and sanctioned by the Treaty.

The Washington Post said that it was only after bombs started exploding in Europe and in the Congress [8.18], that under the pressure of US public opinion and the alarmed NATO allies, the US Administration decided, for tactical reasons, to stick still to the old interpretation of the Treaty in the framework of 'practical policy.' But some of the Governmental officials, including President Reagan, Secretary of State G.Schultz, and Special Adviser to the President and Secretary of State on Arms Control Matters P.Nitze, said many times that the new, 'broader' interpretation of the Treaty is, in their opinion, possible. Thereby they gave to understand that they wanted to preserve the right to return to that interpretation at their convenience.

But what is behind the allegations that the Treaty may be interpreted in a 'broader' context? References are generally made to one of the Agreed Statements attached to the Treaty when it was signed—statement [D]. This statement is represented as allegedly permitting the unlimited development, or even deployment, of ABM systems 'based on new physical principles' (lasers, particle beams, etc.). This interpretation of the statement is contrary to its meaning.

Complementing Article III of the Treaty, this statement does not exclude the advent in the future of antiballistic-missile means based on new physical principles, but only applies to the ABM system deployment areas permitted by the Treaty and again to stationary ground-based systems only—not space-based and not any other systems. Even so, such new means may only be deployed in the permitted area after appropriate consultations of the Parties to the Treaty about specific limitations and appropriate amendments to the Treaty. In other words, statement [D] is aimed at strengthening the provisions of the Treaty that prohibit the deployment of any full-scale ABM systems, and not at abolishing the bans

pursuant to Articles I and V concerning the ABM systems and components based on new physical principles. This is the only interpretation of statement [D] that is possible.

The illegitimacy of the so-called 'broad' or 'liberal' interpretation was stressed not only by the Soviet side, but also by the US officials who were directly involved in the drafting of the Treaty, among them the head of the American delegation at the talks G. Smith and the legal adviser of the delegation J. B. Rhinelander [8.19].

It has been noted above that the SDI undermines not only the US–Soviet ABM Treaty, but also a number of multilateral treaties that have for quite a long time already formed the basis of law and order in space, specifically the Outer Space Treaty of 1967 and the Non-Proliferation Treaty of 1968.

It would be pertinent, in this connection, to refer to *The New York Times*, which considers that the matter of principle in this case is not how one can interpret some formulations, but what is good faith in relations between countries [8.20].

Among the main principles of international law, a special place is occupied by one of the most ancient principles—the principle of abiding in good faith by international obligations (*pacta sunt servanda*). Should this principle not be strictly observed, the very existence of international law and maintenance of normal ordered relations between nations would be impossible. This principle has been fixed legally in a number of very important documents of our days. The fulfillment in good faith of obligations arising from the generally recognized principles and rules of international law and also from the international treaties signed by the USSR became a constitutional principle of Soviet foreign policy. This fundamental requirement of international law is ignored by the national leaders of the USA, when they make many statements about their adherence to the ABM Treaty and other arms control treaties, but at the same time they violate these treaties by their practical activities. There is not much honesty in this policy. Seeking some way of 'legalizing' the program, which is by its very nature incompatible with the country's international obligations, the US Administration is attempting unilaterally to propose a 'new interpretation' of the Treaty, to substitute for notions and terms, to impart the opposite meaning to some of its articles and provisions. Such actions and statements cannot be considered otherwise as violations of the principle of observing in good faith international obligations.

Evidently, the US Administration is well aware of this and is now trying to discredit the USSR by accusing it of alleged violations of some arms control treaties, and at the same time is setting the scene for withdrawing from the ABM Treaty when the Treaty will be too much in the way of further efforts aimed at developing and deploying offensive space-based weapons. The US military leaders even make no efforts to conceal their true intentions. C. Weinberger said that the

USA should consider the possibility of really withdrawing from the ABM Treaty [8.21].

The SDI program also contradicts one of the latest agreed principles of international law and US–Soviet relations—the principle of equality and equal security. This principle acquired a legal force in US–Soviet relations with the signing in 1972 by the leaders of the two countries of a document regulating the foundations of the relations between the two countries. It states: 'The prerequisites for maintaining and strengthening peaceful relations between the USA and the USSR are the recognition of the security interests of the Parties based on the principle of equality and the renunciation of the use or threat of force.' It also says: 'Both sides recognize that efforts to obtain unilateral advantage at the expense of the other, directly or indirectly, are inconsistent with these objectives.' The principle of equal security is also established in other US–Soviet and multilateral agreements. Reliable and equal security for all the states, an aim pursued insistently and actively by the USSR, must be based on political decisions, not on the development of novel weapons.

The SDI program is clearly meant to undermine the established military and strategic balance, to gain unilateral military advantages for the USA. Therefore, it is incompatible with the principle of equality and equal security. The antiballistic-missile weapons to be developed according to the SDI plans can be used to strike against targets in space, in the atmosphere, and on the ground, i.e., they are space-based weapons in the proper sense of the word. This would be bound to trigger an uncontrollable round in the arms race, both defensive and offensive, disrupting the entire arms control process. The deployment of offensive space-based weapons would enhance nobody's security. It would only increase the mistrust in international relations and would render countries less secure.

When President Reagan set forth his SDI plans, he said that its purpose is 'rendering these nuclear weapons impotent and obsolete.' But, after all, the USSR proposed an extremely simple, radical and effective way of solving this problem—completely to do away with the nuclear weapons themselves by the end of the century. If the intentions of the US Administration concurred with the public pronouncements of its spokesmen, there would be no reason for rejecting the Soviet proposal, which would enable both sides in a relatively short time, in historical terms, to abolish weapons of mass destruction and to establish a new barrier to the new–space–arena of the arms race.

The truth lies clearly in another direction. The analysis given in this book indicates that the pseudo-peaceful and defensive facade of the SDI program is required to conceal the intentions of the US Administration to gain a potential for inflicting a disarming nuclear strike on the USSR under the cover of an antiballistic-missile shield. The SDI program is thus a massive attempt to gain strategic superiority for the USA. This is a continuation of the international

policy from a position of force not from a position of law, a complete disregard of US international obligations and of interests of internationl security.

The task of preventing the nuclear holocaust that threatens mankind calls for other measures, primarily a ban on the development, testing, and deployment of space-based weapons, including antisatellite and antiballistic-missile weapons. By banning the use of force in space, and by reinforcing this ban by appropriate material safeguards, international law would create a solid foundations for using space for the benefit of mankind.

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Chapter 9
Spin-offs of SDI research efforts

Not infrequently it is maintained, among other things, that the SDI research and development program would be beneficial for mankind by its contributions to the general progress of science and technology. It is stated that the development of such a system would require concerted efforts of scientists and engineers, efforts which would necessarily lead to breakthroughs in the most promising fields of fundamental research. These include directed-energy sources, future generations of highly sensitive optical devices, computer hardware and software, top quality structural materials, etc.,etc. [9.1, 9.2]

Those assessments stem from the widely held opinion that military R&D efforts have made and continue to make enormous contributions to the technological development of civilization. Looking back at the course of development of armaments during the last decades and their civilian spin-offs, one does not find much supporting evidence for this point of view. Needless to say, a wide and complex scientific effort aimed at developing a space-based ballistic-missile defense heavily subsidized by the federal budget could yield some results useful for civilian purposes. But whereas in earlier times the negative influence of extensive military research on the tempo and nature of progress in science and technology was not always easy to perceive, under present conditions this influence becomes ever more apparent [9.3, 9.4].

An analysis of the effectiveness of military research and the possibility of its spin-offs for peaceful purposes should take into consideration the amount of the resources absorbed, the costs, and the quite specific objectives of military programs. Contrary to popular belief, military R&D programs have never been the main source of innovations. Traditionally, the Pentagon tends to deal with major companies of the military-industrial complex, whereas the chief source of breakthroughs, especially in the post-war US, have been minor laboratories [illegible] The cumbersome and inflexible structures of mammoth industrial combines are not conducive to generating fresh ideas, all the more so that these ideas tend to put out of date and depreciate the already-accumulated production potential [illegible]

The relative inefficiency of military science as a source of new know-how is also borne out by the statistics of US patents. Examination of the largest contractors of the US Department of Defense specializing in military R&D reveals that in the period from 1949 to 1959 these companies received 61,300 patents. In connection with research contracts for the Department of Defense these firms obtained 7,988 patents and only 7 per cent of them found wide commercial application. By way of comparison, the cross-sectional average for the US Patent Office is 50 per cent.

During the years 1949–59, 15 major military industrial organizations in the US spent $7.9 billion on R&D related to defense, and filed 2,190 patent applications related to that research. The same firms during the same period of time invested $5.8 billion into civilian research studies, which produced 23,880 patents [9.7].

One important feature of military research programs is that their aims are but weakly related to the rational needs of human civilization. Commercial applications of the results of military investigations are on the decline. Whereas piston-engined airplanes could double for civilian purposes nearly without modifications, and the advent of jet propulsion has led to the emergence of high-velocity air liners, the development of the supersonic liner has run into serious difficulties and the prospects for this kind of transportation in the near future are remote. So the Anglo-French *Concorde* is only used for prestige.

This is all the more characteristic of specialized military developments. Further developments in aerospace research revealed an ever widening gap between the needs of the civilian and military markets. The enormous expenses required for the Stealth technology aimed at reducing the radar cross-section of aircraft, developing radar-absorbent coatings, developing military aircraft capable of flying at low altitudes and high velocities—these are all problems of no concern for civilian aviation.

The results of research and development in connection with modern missile complexes, sophisticated and precision surveillance and aiming systems, highly specialized electronic equipment such as jamming devices, will hardly find their practical applications for peaceful purposes. No wonder, then, that at present military research spin-offs are shifting ever more in the direction of technological processes, materials, etc., invented during the course of development in the military sector, since the development *per se* is of no use to civilian industries.

Admittedly, some spin-offs are useful for civilian applications, but it is quite obvious, however, that they could be obtained at a lower cost if they were oriented from the very beginning at civilian goals and were financed as generously as the military efforts. Consequently, the role of the military industries as generators of breakthroughs has never been spectacular and it continues to decline. Even the very process of transferring scientific and technological

knowledge from the military sector to industries becomes ever more cumbersome and costly. The government tries every trick in the contract system, sponsors special exhibitions to inform civilian firms about novel military developments, and spends a great deal of money to overcome the secrecy barrier. And still these efforts are exceedingly ineffective. President Commission on Industrial Competitiveness admitted in its report [illegible] that military research programs are so specialized and require so much time before they bear fruit that they are of small use for the industries that meet the needs of the population. What is more, the Commission recognized that the Pentagon itself is now engaged in an active search for inventions coming from the civilian sector, and the historical direction of the flow of technology has reversed.

Analysts of the influence of military R&D on general technological progress often mention the important role played by the funds alloted to military studies in creating a market for novel products. Actually in the 1950–60s the Pentagon took hold of discoveries and inventions in the civilian sector and, sparing no effort and money, brought them up to their practical military applications. Of course, it then played the important role of the guaranteed primary user, one that was buying up products too sophisticated and expensive to be realized immediately in the civilian market. In recent years, however, the importance of the Department of Defense as a primary consumer of high technology products, i.e.,innovations that lay the foundation for a new area of technology, has also declined markedly [9.9]. The civilian market has been saturated with sophisticated high technology products, which brings back to the manufacturing firms enough money to finance their own research and development efforts. While in 1969 the federal government bought 36 per cent of the total semiconductor output in the US, in 1978 this figure was only a shade over 10 per cent [illegible]. And this decline occurred not due to sagging military demand, but due to the growing nondefense demand for semiconductors.

Comparison of the experience gained, say, by the US and Japan yields convincing evidence that direct civilian studies are more cost-effective than nondefense spin-offs of military R&D programs [illegible]. After all, military and civilian investigations in the same field are carried out with fundamentally differing objectives. Military studies concentrate exclusively on meeting the required technical and military specifications taking little heed of costs. Therefore, many civilian spin-off products of military research turn out to be noncompetitive because of the high costs involved. According to the Stockholm International Peace Research Institute [illegible], development costs in military industries are on the average 20 times higher than in comparable nondefense branches. One can thus safely claim that a redistribution of R&D federal funds in favour of the military component on the whole impedes scientific and technological progress.

The negative implications of military studies would be especially conspicuous in the case of the proposed SDI research program, since the US is plann-

ing to include many scientists all over the world in these efforts. The SDI management are looking forward to internationalizing their program and pooling the best international brainpower And this would in turn mean that a large group of scientists in various countries would be diverted from solving some urgent problems with the inevitalbe result that the tempo of development of human civilization would decline [9.12].

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Conclusion

The multidisciplinary study, carried out by the Working Group of the Soviet Scientists' Committee for the Defense of Peace Against Nuclear Threat, of a number of technological, strategic and political aspects of the development and deployment by the USA of a comprehensive space-based ballistic-missile-defense system, the potential implications of the proposed system for the stability of the strategic balance, parity and international security yielded the following conclusions.

The system would clearly be unable to 'render nuclear weapons impotent and obsolete,' to provide reliable protection for US territory, and even less so for US's West European allies or other regions of the world. Various limited forms of a BMD, too, would not improve the stability of the strategic balance. Therefore, the concept of security achieved allegedly by deploying new military and technological capabilities, primarily antimissile systems, would in reality provide no escape from the nuclear impasse. Moreover, should this concept be realized, nuclear war would become more likely.

In this connection, we can only view the US plans to deploy a BMD as a desire to make use of the country's scientific and technological potential to achieve military superiority. The USSR has enormous economic and scientific potential, rich historical experience in many respects, including the maintaining of a rough strategic parity. Thus the hopes, which are not so widely publicized but clearly cherished by the US Government, to gain some political and military advantages over the USSR and its allies by developing and deploying a BMD are in vain.

The same goes for the hopes of some US politicians to cripple the USSR economically by forcing it into an arms race in space accompanied by a new round of the arms race in nuclear and conventional weapons. One of the most important conclusions of the analysis performed by the Committee members and invited experts was that the USSR has a wide spectrum of feasible, accessible and relatively cheap ways and means to thwart the new threat to the security of the USSR and its allies that would be posed by the proposed BMD which may be used to guarantee the impunity of a first strike.

The comprehensive systems analysis of the issue of countermeasures to a space-based ballistic-missile-defense system shows that the costs of some complexes of countermeasures may make up as little as several per cent of the BMD's costs. Some other forms and combinations of means for nullifying or overwhelming a BMD appear to be more costly, especially those which provide for a higher resistance to a first strike. But either way, any combination of countermeasures invariably equals only a fraction of the estimated costs of a planned BMD. Furthermore, such countermeasures, when used in combination, are less vulnerable and far more stable as a system than a full-scale BMD with at least some of its components space-based.

Thus, if, in violation of the ABM Treaty and other international instruments, despite the opinion of the majority of scientists of the world and protests of the international community and common sense, the leading political, military and industrial circles of the USA embark on the program for developing and deploying the 'Star Wars' weapons, the USSR will find a wide variety of possibilities to ensure its security under the new conditions, to restore the strategic parity. In that case, as was repeatedly stressed by the Soviet political and military leadership, the USSR will never follow a path the adventurist circles of the USA would like it to follow.

The present strategic landscape is an exceptionally complicated macrosystem of weapons and other components whose stability depends on the behavior of each side. Should the USA try to tip the balance in its favor, the USSR would invariably restore it, albeit at a higher, and hence more precarious, level. As a result, the risk of a nuclear war would be higher, among other things, due to accidental errors in strategic assessments and possible self-activation caused by failures in components. Therefore, the proposed comprehensive BMD, even if a far cry from what the interested lobbyists claim it would be in terms of efficiency, and even if neutralizable by the other side in order to retain its retaliatory capabilities, would markedly impair the stability of the balance and increase the risks of a nuclear holocaust.

The development of a stable network of fairly invulnerable countermeasures in response to the deployment of a BMD would substantially reduce the advantages of a first strike as compared with the situation when both sides had space-based ballistic-missile-defense systems. A 'both sides have a space-based BMD' scenario would have inherent in it a measure of strategic instability, since the antimissile space-based weapons of one side could knock out, as a prelude, the counterpart weapons of the other side. In doing so, the attacker would spend an insignificant part of its resources.

There is the danger that the acquisition of a BMD would provoke some people in the US Administration to actively use military force as a main tool of international policy, for example, by waging all sorts of local wars, including nuclear wars, seeking to conclude them, to use the language of the Pentagon, 'on terms favorable for the USA.' It is no accident that many proponents of the SDI

also act as advocates and authors of a variety of concepts of nuclear warfare that allege, contrary to the many independent studies, that a nuclear war can be won. The Soviet political and military leadership rejects this allegation. The new version of the Program of the Communist Party of the Soviet Union states clearly and unequivocally that in a nuclear war there would be neither victors nor vanquished.

It is a positive element of international life that the US Administration, too, despite the statements made early in the 1980s, came to recognize officially that it would be impossible to win a nuclear war. This found its reflection, in particular, in the US–Soviet Joint Statement at the Geneva summit in November 1985. It says that a nuclear war cannot be won and must never be fought. It is also stressed that any conflict between the USA and the USSR could have catastrophic consequences, whence the need to prevent any war between these two nations, whether nuclear or conventional. The sides have also stated that they would not seek military superiority.

Regrettably, the way the US armed forces are being built and the doctrinal thinking of the US Department of Defense still show distinct tendencies to the contrary.

Seeking a victory in a nuclear war, even placing reliance on the massive use of offensive space-based weapons, is extremely dangerous. If in earlier days a state proceeded from unrealistic and adventurist concepts of using 'methods of force' in policy, methods that in some way or another relied on the employment of the state's military machine, i.e.,on war, this might mean at worst the danger for the state to suffer a severe defeat in the war it has begun. Now, in the age of nuclear-armed missiles, such an irresponsible attitude must be approached differently. Those state and military leaders who are now guided by concepts that fail to take into account the nature of war today are bound, should they wage such a war, to doom their people, along with humanity at large.

This and the true interests of the equal and mutual security of the USA and the USSR, and those of the entire international community, call upon everyone to save the ABM Treaty of 1972, to struggle for curbing the arms race. This approach responds to the need for enhancing the stability of strategic balance for reducing the probability of a nuclear war. Retaining the regime of strict limitations on ABM systems and banning offensive space-based weapons are the most important conditions under which it would be possible to control and phase out nuclear weapons down to their complete and universal elimination, as it is proposed in the January 15,1986 Statement of General Secretary of the Central Committee of the CPSU, M.S.Gorbachev.

To stop the nuclear arms race, to prevent the buildup of ever more destabilizing systems of superaccurate weapons, and hence to avert the threat of a nuclear war requires also such a step as the complete and universal prohibition of nuclear tests. If all the tests of nuclear weapons were stopped, all the ways to improve nuclear arms would be ruled out automatically.

And if the Soviet proposals to reduce by 50 per cent the US and Soviet arsenals of nuclear missiles capable of reaching the territories of the two countries were realized through mutual agreements, this could become an important landmark on the path to completely ridding the world from nuclear weapons by the year 2000.

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The night after...

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Edited by Yevgeni Velikhov, Vice-President, USSR Acad. Sc.

This book covers the main research by Soviet scientists, conducted under the auspices of the Soviet Scientists' Committee for the Defense of Peace Against Nuclear Threat, on the consequences of a nuclear war. Leading Soviet scientists describe in a popular manner, but on a high scientific level, the essence of those vital investigations, which may well become the turning point in this extremely dangerous and senseless nuclear arms race. The scientists' conclusion is clear and unambiguous: the use of even a fraction of the nuclear arsenal that exists in the world today would result in a 'nuclear night' and a 'nuclear winter', which would ultimately cause unprecedented global ecological disaster. Such an 'atmospheric bomb' would mean the extermination of all living things on Earth.

Weaponry in space:
The dilemma of security

Edited by Yevgeni Velikhov,
Vice-President, USSR Acad.Sc.
Roald Sagdeev,
Member, USSR Acad.Sc.
Andrei Kokoshin,
D.Sc.(History), Prof.

This book, produced by the Soviet Scientists' Committee for the Defense of Peace Against Nuclear Threat, is a comprehensive analysis of the technological, strategic, political and legal aspects of the proposed space-based antimissile system. The potentialities and real limitations of the various hypothetical components of a major antimissile system are considered in much detail. The authors make a strong case that it cannot be regarded as a purely defensive system. It is rather a novel kind of offensive weapons, which, if deployed, would trigger a new round of arms race in all areas and would increase the probability of nuclear war.

The book will be of interest for the lay and specialist reader.